Image analysis of hydrophobicity and dielectric property of polymer insulating material

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Abstract: Hydrophobicity of polymeric insulating material surface such as silicone rubber insulator was studied by using image data analysis of the sample surface. Hydrophobicity of polymer was evaluated by the motion of water droplets on the sample surface under AC high field application. The vibration image of the water droplets was taken by CCD camcorder. The video image was divided into each image frame and the image indexes such as size and shape factor of the droplets were evaluated for each image frame. Then, the time variation of the image indexes of sample surface during high electric field application was evaluated, where electric field deformed the droplets.

The motion of the water droplet was also determined by measuring the dielectric property of silicone rubber surface using a pair of inter-digital electrodes. The motion of water droplets was detected by using unbalance operation of current comparator type Capacitance Bridge system. The changes in dielectric loss current and capacitive current by the deformation of the water droplets were measured for every one cycle of applied AC field. To compare these results the degradation of hydrophobicity of polymer insulator is defined more accurately.

Introduction

Polymeric insulating materials are widely used in the manufacture of weather-sheds of outdoor insulators. Silicone rubber (SIR) especially has excellent hydrophobic property in addition to its excellent electrical, mechanical and chemical characteristics. The usage is expanding rapidly as an electric insulation material typically under the heavy contaminated environment. Therefore, it is very important to study the degradation of hydrophobicity of polymer surface as one of the indexes of its initial deterioration processes.

The hydrophobicity is usually measured by contact angle of a droplet of distilled water on the sample surface. However, it sometimes shows hysteresis, time dependence and location dependence of the measured point. Therefore, hydrophobic image of the surface is recently used to determine the hydrophobicity class (STRI's HC level from 1 to 7) [1]. A digital image processing method for estimating the level of hydrophobicity of specimens are reported in [2, 3].

This paper studies the motion of the water droplets on the SIR surface during AC high field application. Image data indexes such as size of the water droplets are evaluated to discuss the HC levels. This phenome-non is also detected by the change in dielectric property measured by same electrode on the SIR surface [4]. Electric field dependence of dielectric properties, such as AC loss factor and the change in capacitance, have hysteresis when the residual contact angle becomes smaller.

These dynamic motion study of water droplets on the polymer can diagnosis the vibration of the water droplets on the polymer surface during high AC voltage application. This vibration may initiate the flashover on the insulator surface and, thereafter, the degradation of the material starts.

Sample and Experimental Procedure

HTV SIR sample having 60x50x6mm is used. A pair of inter-digital electrodes which was made by stainless steel is set on the sample surface. Between the inter-digital electrodes, water droplets were put on the sample surface. The photographic view of the sample and electrodes are shown in Fig.1. AC high field is applied to the electrodes and the motion of the droplets are measured by the image analysis using digital camcorder and also by the dielectric measurement of AC loss current and capacitive current for each one cycle of AC

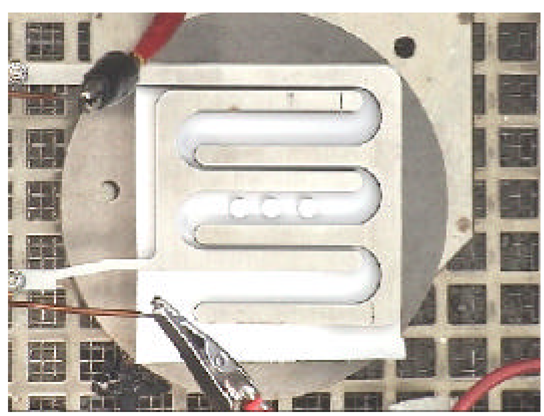

Figure 1: Inter-digital electrodes and water droplets on HTV-SIR sample surface.

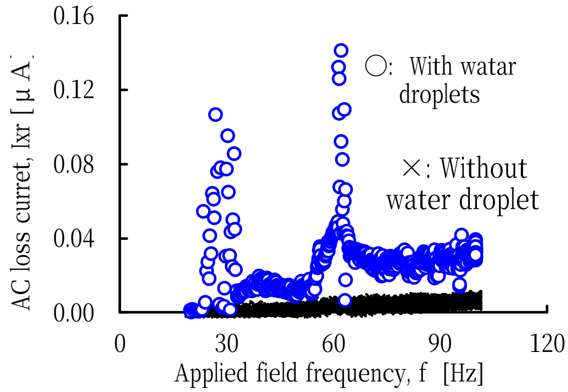

Figure 2: Typical frequency dependence of AC loss current measured by the inter-digital electrodes with and without water droplets on the HTV-SIR surface.

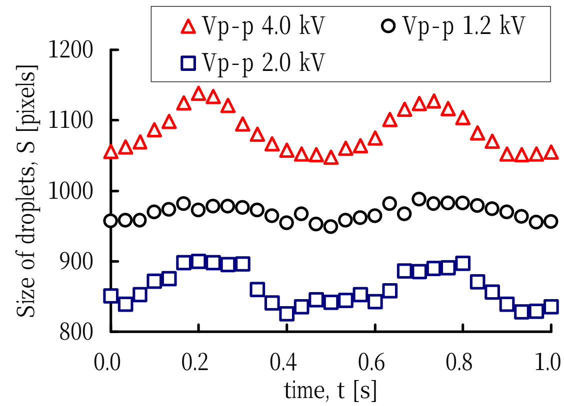

Figure 4: Change in the image size of the water droplets under 29 Hz AC field application. Parameter: Magnitude of AC applied field between the inter-digital electrodes. The volume of the water droplets were 20 μl.

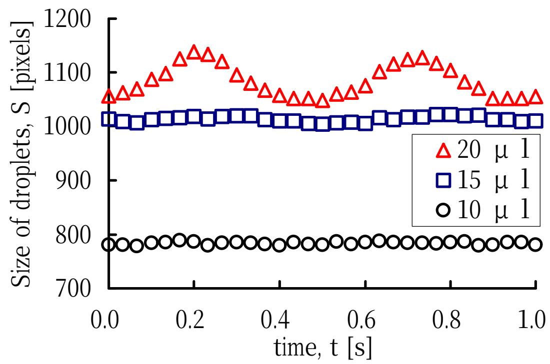

Figure 3: Change in the image size of the water droplets under 29 Hz AC field application. Parameter: Volume of the water droplets between the inter-digital electrodes.

field. Three water droplets are used and their mean value of the droplet image size is measured.

Results and Discussions

Frequency dependence of AC loss current

Figure 2 shows typical frequency dependence of AC loss current measured by the inter-digital electrodes with and without water droplets on HTV-SIR specimen. Around 30 and 60 Hz, there are resonance of the vibration of the water droplets and the loss currents are increased. Capacitive current also shows the resonance at same frequencies.

This resonance frequency depends on the size of water droplets and also on the surface free energies of both the water droplets and the sample surface. This vibration of water droplets may caused by the Coulomb force between the applied AC field and the dielectric polarization charges on the water droplets.

Effect of volume of water droplets on the vibration

Figure 3 shows the mean size of three water droplets between the inter-digital electrodes. The applied field frequency is 29 Hz and frame rate of the image is 30 FPS. When applying 30Hz electric field, image data analysis can not detect the resonance vibration of the water droplets, however, the vibration is larger around 30 Hz (Fig.2). Increasing the volume of the water droplets, the mean size of the droplets increases and the vibration magnitude also increases. In this measurement 20 μl water droplets show most large vibration of the droplets during AC field application. More large size of the water droplet shunts between the inter-digital electrodes during AC high-field application. Figure 3 also shows two cycles of vibration. The applied electric field frequency was 29 Hz and the frame rate of the images was 30 FPS. Therefore, it means the vibration frequency of water droplets was double of the applied field frequency.

Effect of magnitude of applied field on the vibration

Figure 4 shows the one except the magnitude of applied AC field is changed. Increasing the applied AC electric field the magnitude of the vibration of water droplets increases. The frequency of the vibrations is same and it is double of the applied AC field.

Effect of surface free energy of water droplets on the vibration

Figure 5 shows the one except the magnitude of surface free energy of the water droplets is changed. Decreasing the surface free energy of water droplets, the size of

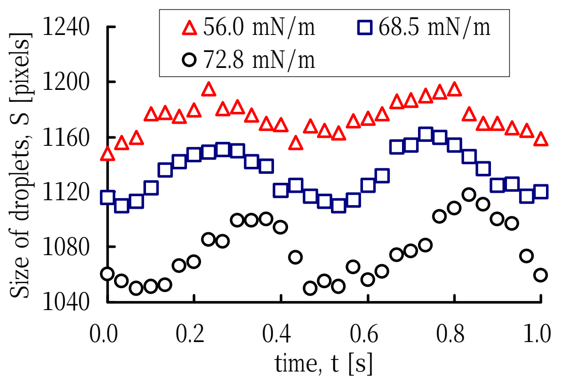

Figure 5: Change in the size of the water droplets under 29 Hz AC field application. Parameter: Surface free energy of the water droplets.

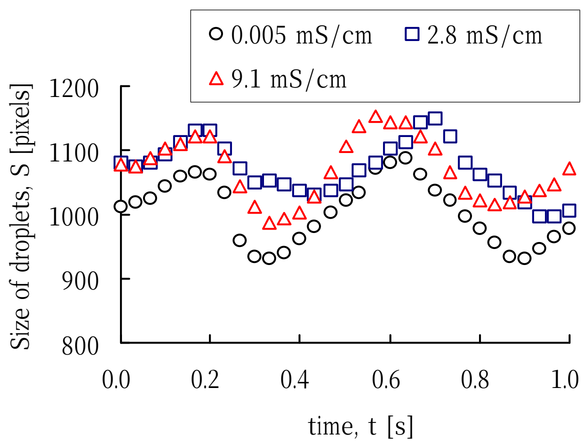

Figure 6: Conductivity dependence of the vibration of water droplets. Parameter: conductivity of the water droplets.

water droplets increases. However, the magnitude of the vibration of water droplets is decreased. The frequency of the vibration is same as Figs.2 to 4.

Effect of Conductivity of water droplets on the vibration

Figure 6 shows the one except the magnitude of conductivity of the water droplets is changed. Increasing the conductivity of water droplets there is no significant change in the behavior of the vibration. The size of the droplets and the magnitude of the vibration show no remarkable changes. Therefore, if the hydrophobicity of the SIR surface is good, change in the conductivity of water droplets makes no change in the vibration during AC high field application.

Temperature Dependence of Mean Size of the Water Droplets on SIR

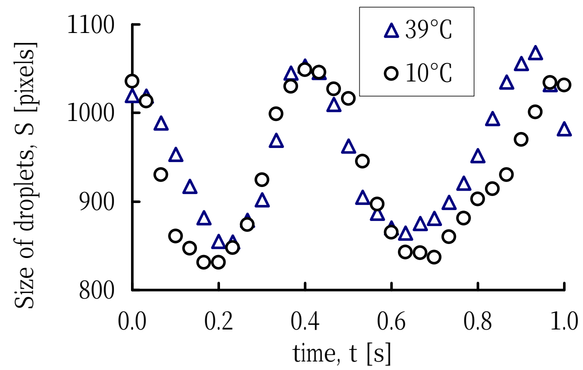

Figure 7: Change in the size of the water droplets under 29 Hz AC field application. Parameter: Temperature of the measurement. Both SIR sample and water droplets are at 10 or 39 °C. Distilled water is used to make water droplets: Conductivity, 5 μS/cm, Surface free energy 72.8 mN/m at room temperature.

Figure 7 shows the temperature dependence of mean size of droplets on the HTV-SIR surface. The measurement of the image was done at 10 and 39 °C. Increasing the temperature, the surface free energies of both the water droplets and HTV-SIR are decreased.

The decrease of surface free energy of the water droplets decrease the contact angle and, therefore, increase the size of water droplet image when the volume of droplet was same. The decrease of surface free energy of the solid, however, increase the hydrophobicity and increase the contact angle of water. It decrease the size of contact area and the size of the image of water droplets. Increasing the experimental temperature, both contrastive phenomena occurs simultaneously. In this experiment, Fig.7 shows no significant change in the vibration behavior of the droplets. However, more detailed measurement should done to evaluate the effect of temperature for the hydrophobic properties.

Electric field dependence of dielectric property of water droplets on HTV-SIR

This vibration phenomenon of water droplets under AC field application is also detected by the change in dielectric property measured by same electrodes on the SIR surface [4]. Electric field dependence of dielectric properties, such as change in the capacitive current, relate to the behavior of water droplets on SIR surface and, therefore, hydrophobicity of the sample. If the water droplet moves by the application of AC field, the change in the capacitive current occurs.

When the sample surface has excellent hydrophobic property, its residual contact angle is larger. In this

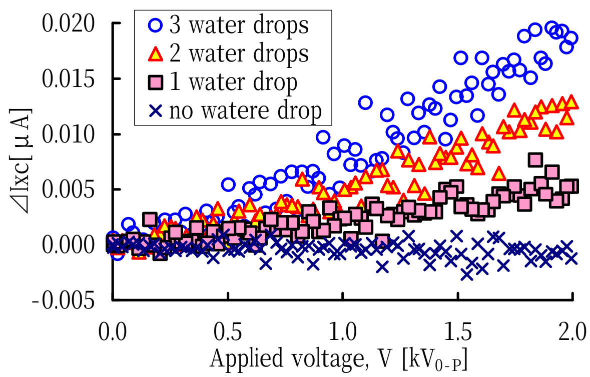

Figure 8: Electric field dependence of ΔIxc of the HTV-SIR surface with and without water droplets. Parameter: Number of distilled water droplets is changed from 0 to 3.

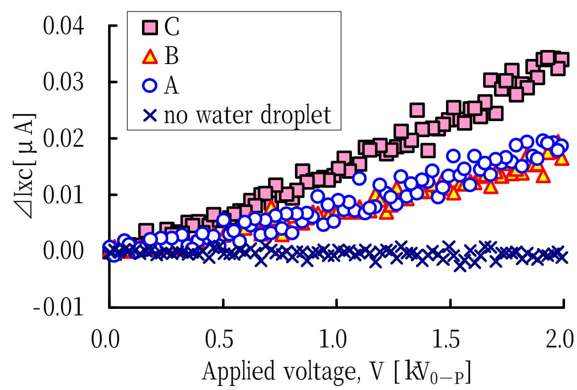

Figure 9: Electric field dependence of ΔIxc of the HTV-SIR surface with three water droplets. Parameter: Conductivity and surface free energy of water droplets. A; Distilled water, 72.8 mN/m, 5μS/cm, B; salt solution, 72.8mN/m, 9600 μS/cm, C; solution with low surface energy, 56.0 mN/m, 120μS/cm.

case, water droplets on the SIR show vibration during the application of AC high field. This vibration phenomenon depends on the size of the droplets and on the magnitude of applied field.

Figure 8 shows the electric field dependence of ΔIxc of the HTV-SIR surface with and without water droplets. The number of the water droplets is changed from 0 to 3 drops. The measuring bridge system is balanced at without water droplet. Therefore, without water droplets there is no ΔIxc current was detected. Increasing the number of water droplets on SIR surface, the capacitive current increases. The electric field dependence of the capacitive current shows small nonlinear increase and it relates to the vibration of water droplets under AC high field. The hysteresis of the electric field dependence is small. These results mean the hydrophobicity of the sample surface is well.

Figure 9 shows the electric field dependence of ΔIxc of the HTV-SIR surface with water droplets which have different conductivity and surface free energy. A (Distilled water, 72.8 mN/m 5mS/cm) and B (salt solution, 72.8mN/m, 9600 mS/cm) show almost same electric field dependence. C (solution with low surface energy, 56.0 mN/m, 120mS/cm) shows, however, large electric field dependence compared with others. Therefore, increasing the conductivity of water droplets does not affect to the change in capacitive current but the decrease of surface free energy of the water droplets increases the capacitive current.

These results mean the measurement of dielectric properties typically change in capacitive current can detect the change in the hydrophobicity of the solid surface. If the hydrophobicity of the surface is well dielectric property of the sample is small and its electric field dependence shows small nonlinear relation and small hysteresis. However, it shows vibration of water droplets on resonance frequency.

In this study, this resonance frequency is double of applied AC field and it depend on the size and surface free energies of both solid and water droplets. However, this vibration of the water droplets under AC high field also shows fundamental and third and higher harmonics during more high AC field application. The details are continue to study.

Acknowledgment

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