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Discharge behavior and dielectric performance of artificially polluted hydrophobic silicone rubber

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ABSTRACT

Flashover voltage and discharges behavior were investigated with silicone rubber (SiR) polluted with fog, red clay or carbon particles. For a SiR polluted with carbon, partial discharges occur between water droplets and form interspersed dry bands. For a SiR polluted with red clay, the leakage current induces uniform dry bands and dry-band arc discharges. Because flashover occurs through the dry bands, the noticeable difference in flashover voltage between the polluting materials is not seen. The pollution deposit changes the surface state and causes partial discharges which lead large leakage current, however, the partial discharges don't significantly lower insulation performance.

1. Introduction

Electric power equipment such as a polymer housing surge arrester [1] and a polymer housing insulator [2] contributes to reduce power failure owing to overvoltage. Such power equipment should contain high insulation performance which can withstand sea wind and high mechanical strength for external force. Porcelain has been widely used as housing material for electric power equipment. Inorganic materials such as porcelain and glass have good insulating characteristics and anti-weather aging performance. However, they are poor in work efficiency because of the heavy weight. Additionally, dielectric strength becomes low as the material surface is polluted.

Polymeric material has some excellent properties such as mechanical strength, light weight design, hydrophobicity, and anti-pollution performance. SiR [3] has been used on electric power equipment instead of porcelain. However, application of polymeric components to electric power systems is limited, and Japan is one of the counties. Japanese climate and natural disasters are one of the major causes for concern [4], and the reduction of dielectric strength with the long-term usage is anxious. Because the polymeric equipment is used under various conditions, many kinds of contaminated deposits are confirmed [5,6]. Therefore, it is important to investigate the influence of the pollution deposit on the discharges behavior and the dielectric strength.

Incidentally, although hydrophobicity prevents to form a water film or a water - conductive path [7–9], the leakage current of polymeric equipment increases after the hydrophobicity of the polymer surface decreases. Until now, we evaluate hydrophobicity of SiR by a dynamic drop test [10]. The decrease of hydrophobicity is caused by the water drop-falling, partial discharges or the dry-band arc discharges on the surface. Pollution deposits may at least have an influence on hydrophobicity and discharge behavior on the polymer surface. Thus, the decrease of hydrophobicity, the leakage current, and the discharge phenomenon are inseparably linked.

Many investigations are attempting to understand the flashover and aging behavior of SiR under various polluting concentrations. However, they focus on flashover voltage of SiR with a contamination layer consisting of sodium chloride [11,12]. The pollution dependence on the discharges behavior as well as the insulation performance of SiR polluted with non-soluble material is not sufficiently clear yet. In this study, measurement of ac flashover voltage and observation of partial or dry-band arc discharges were carried out with some artificially heavy-polluted SiR samples, on which we used carbon particles and red clay as polluting material. We have developed a polymer housing arrester for rolling stock, and carbon particles have been seen on the surface. Red clay is chosen as non-conductive material because it is widely detectable on the surface of polymeric equipment used outdoors. Additionally, we observed the change in the surface hydrophobicity. Based on the obtained results, we evaluate the pollution dependence on the discharges behavior as well as the insulation performance of heavy-polluted SiR samples.

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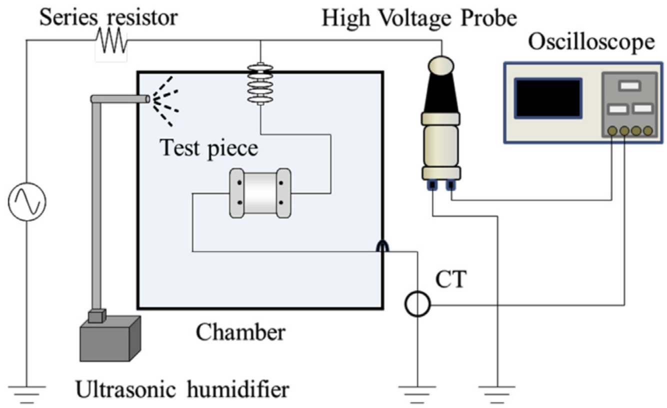

Fig. 1. Experimental setup used for measurements of ac flashover voltage and leakage current in a fog chamber.

2. Experimental

Fig. 1 shows the experimental setup used for measurement of ac flashover voltage, and the electrodes configuration is shown in Fig. 2. We use SiR samples of 50 mm in width and 4 mm in thickness as test specimens. A pair of electrodes made of stainless steel is arranged on a SiR sample. The SiR samples were artificially polluted with red clay or carbon particles. The insoluble deposit density was set at about 1 mg/cm^2. For fixing the red clay on a SiR sample, the turbid liquid in which the red clay to be a target density and deionized water were mixed was poured into a vessel where the sample was placed on the bottom. After that, the natural drying was carried out for 5 days. On the other hand, for fixing carbon particles on a SiR sample, the carbon particles were sprayed by a sprayer. Carbon particles are found on the surface of polymeric equipment for pantagraph of rolling stock. Red clay is widely observed on the surface of polymeric equipment used outdoors. These two types of pollution reduce the equivalent hydrophobicity of SiR surface and cause discharges.

The distance (g) between a pair of plane electrodes was set to 10, 20, 30, and 40 mm. We arranged a SiR sample in the middle of a fog chamber ($1.5 \times 1.5 \times 1.5\,m^3$) [10]. We evaluate the hydrophobic character of SiR by a dynamic drop test [11,12] where the sample inclination is defined by 60° with respect to a ground face. It is found out that the water drop-falling also decrease the hydrophobicity. Also, for example, the polymer insulator shed leans, and the polymer insulator is sometimes used in an inclining state. From these kinds of reasons, we set the sample inclination to 60°. Purified water 0.1 mS/cm in conductivity with a spray rate of 1.2 l/h was sprayed in the fog chamber using an ultrasonic humidifier. The brow off nozzle 30 mm in diameter is positioned at a height greater than a SiR sample, and the average mist

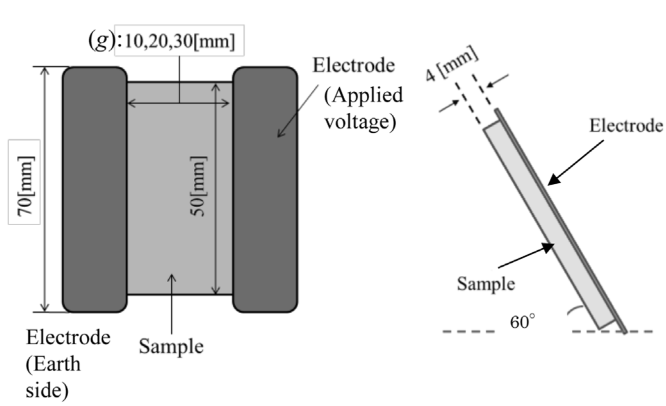

Fig. 2. Electrodes configuration and its inclination with a SiR sample. High voltage is applied to the right-hand electrode.

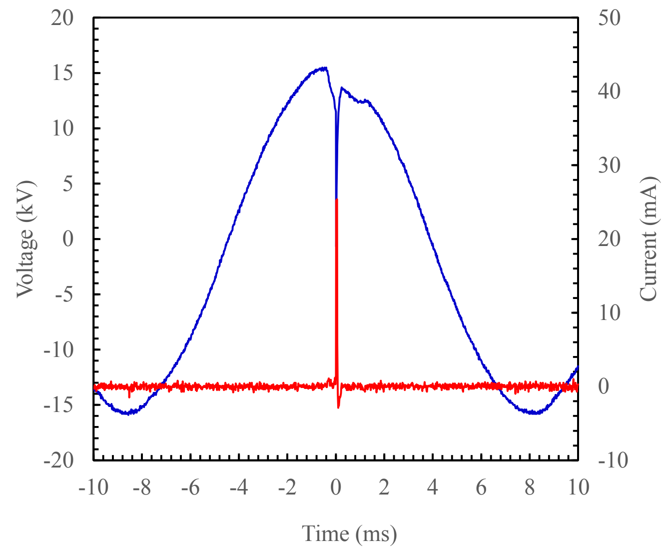

Fig. 3. Waveforms of voltage and current when flashover occurs at $t = 0$ ms. The voltage suddenly drops to 0 V when the current pulse appears.

diameter is about 3 μm. We applied 60 Hz ac voltage after the fog was supplied for 120 min which was required for forming the numerous water droplets on a SiR sample. The rate of rise of voltage is equal to 0.1 kV/s, which made our observation of discharges easy. The maximum output voltage and the rated capacity of our power source of which the input voltage is 200 V are 30 kV and 3 MVA, respectively.

The flashover voltage was recorded with a PC through an analogue–digital (A/D) converter board with a sampling frequency of 10 MS/s. We repeated 5-times ac flashover tests on each pollution deposit and obtained an averaged value. The flashover voltage was defined as a voltage value at which applied voltage suddenly decreased to nearly 0 V, as shown in Fig. 3.

The observation of partial or dry-band arc discharges [11] was performed by using a high-speed video camera with 250 fps. When we took time - lapsed photography, a fog chamber door as small as 0.8 m square was opened after the fog was supplied for 120 min. Although the fog density in the fog chamber decreased, the surface of samples has been already covered with water droplets. Fig. 4 shows the states of water droplets just after the fog chamber door was opened. For the case of a virgin SiR sample, the shape of water droplet has a round shape and its diameter is in the range of 0.2 mm–0.5 mm. According to a STRI method [9], a hydrophobicity level is recognized as HC1 where only discrete droplets are formed. The contact angle (CA) for the majority of droplets is 80° or larger. (HC2: Only discrete droplets are formed; CA is included between 50° and 80° for the majority of droplets.) The diameter becomes larger a little and an ellipse shape for the case of a SiR sample polluted with carbon particles. Because they are no longer circular, an equivalent hydrophobicity level is recognized as HC3. Additionally, for the case of a SiR sample polluted with red clay, hydrophobicity is almost disappeared because the red clay absorbs water. The continuous water film forms over the whole test area, and then an equivalent hydrophobicity level is recognized as HC6. These characteristics are independent on the distance (g) because polluting materials uniformly distribute. In addition, water droplets uniformly distribute and their diameters are smaller than g.

3. Experimental results

Fig. 5 shows dependence of flashover voltage on the distance (g) between a pair of plane electrodes arranged on the SiR surface. An averaged flashover voltage at $g = 40$ mm, obtained from 5 virgin samples, could not be contained because it was higher than 30 kV