Paper

Electrical Performances of RTV Silicone Rubber Coatings in Salt-fog and Rotating Wheel Dip Tests

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The fundamental properties of room temperature vulcanizing silicone rubber (RTV) coatings, which have been applied to improve contamination performances of ceramic insulators, are investigated. Leakage current on plastic substrates and actual ceramic insulators coated with RTV in salt-fog and rotating wheel dip tests are evaluated. Roles of alumina trihydrate (ATH) filler level, filler particle size, filler surface treatment and type of coating substrates on electrical performances and lifetimes of RTV-coated insulators are investigated. In salt-fog conditions, RTV coatings can successfully suppress leakage current and dry-band arcing on bisphenolic epoxy, acryl and ceramic insulators. The reduction magnitude of leakage current levels is not dependent on ATH filler level in the range of 0-50% wt. When RTV coatings are dipped into saline water and then energized (in rotating wheel dip test), leakage current and dry-band arcing accompanied by it are allowed to develop. ATH filler level, filler particle size, filler surface treatment and type of coating substrates, all the parameters affect electrical performances and lifetimes of RTV-coated insulators. It is revealed that, for RTV coatings, neat coating preparation and adhesion between the substrates and coatings are more important than tracking and erosion suppression by adding high level ATH filler.

Keywords: outdoor insulation, RTV coatings, alumina trihydrate filler, salt-fog test, rotating wheel dip test

1. Introduction

Ceramic insulators used in high voltage (HV) outdoor power systems and apparatus have a long history over one century. Ceramics are much more stable against electrical and environmental stresses than polymeric materials. Technologies and experiences to utilize them are well established. However, ceramics having high surface free energies allow readily electrolytic water films to form thereon in wet and contaminated conditions, which allows uncontrolled leakage current leading to flashover and power loss [1-7]. Power outages resulting from flashover along insulators occur occasionally in power facilities, in particular substations in contaminated areas. For ceramic insulators of which surfaces are readily wetted, gaining leakage distance or modifying insulator shape has been an effective way to enhance the resistance to leakage current development and flashover. Removing contamination deposited on insulators by water washing is also an effective way, however it is expensive and it is difficult to estimate washing time and frequency. Silicone grease that is able to provide hydrophobicity to insulator surfaces and to encapsulate contaminants giving electrical conductivity has been applied to suppress leakage current. However, once mobility of the grease is lost by excessive encapsulation of contaminants, this induces local dry-band arcing and can cause tracking and cracking for base ceramics [8]. In addition, painting and removing grease are costly and a disposal of grease annoys power utilities. Room temperature vulcanizing silicone rubber (RTV) coatings, which do not need special treatments to be cured in outdoors, are expected as a definitive method to improve contamination performances of ceramic insulators by providing a stable hydrophobiciity [9-13]. They needs much less amount than grease and can be installed much faster by being sprayed [8]. RTV coatings of thickness less than a few mm would behave differently from bulk silicone rubbers, and lifetime estimation and breakdown mechanisms for RTV coatings have not been well understood. In this paper, fundamental performances of RTV coating are evaluated by employing salt-fog (SF) and rotating wheel dip (RWD) test. Roles of filler level, filler particle size, filler surface treatment, type of coating substrates and test conditions (applied voltage and conductivity of electrolytic water) on electrical performances of RTV coating are studied.

2. Experimental

2.1 Preparation of RTV Coatings

Polydimethylsiloxane of a basic polymer of liquid RTV silicone, silica reinforcer and catalytic agent which are dispersed in carrier solvent of xylene with alumina trihydrate (ATH) filler are coated on actual ceramic insulators and rod plastic substrates. Bisphenolic and cycloaliphatic type epoxy resins (BPE and CAE, respectively) filled with 66.7% wt quartz silica powder and unfilled acrylic resin are used for rod substrates. Dipping is made in coating RTV on rod plastics. RTV is also coated on 180S suspension type porcelain insulators (leakage distance: 285 mm) and ceramic arresters (leakage distance: 330 mm) for 6.6 kV power distribution with the aid of a fine paint brush. The arrangement of suspension type porcelain insulators and ceramic arresters evaluated in the SF chamber ($1\times1\times1$ m^3) is shown in Fig. 1. The diameters of BPE and CAE substrate rods and that of acrylic rod are 26 and 21 mm, respectively. After the completion of vulcanization at room temperature for, at least, 2 days, the RTV-coated samples are presented to SF and RWD tests.

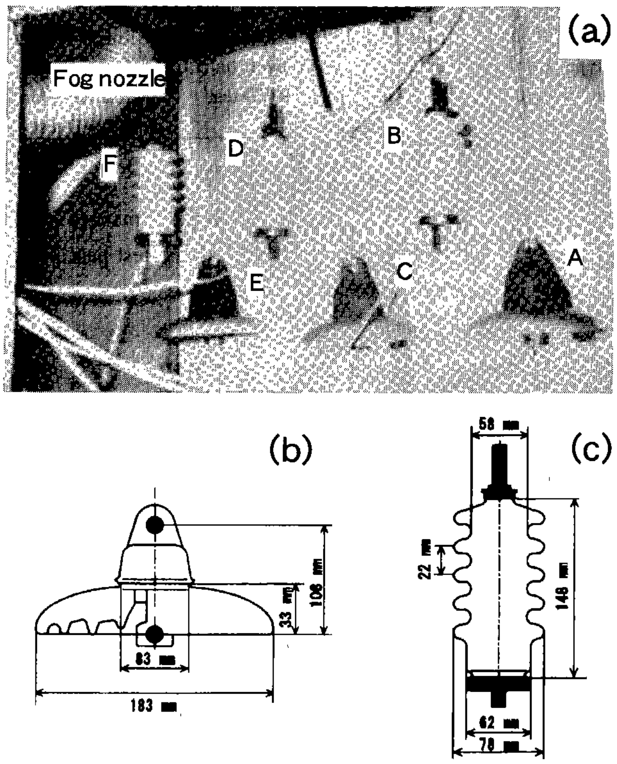

Fig. 1. Arrangement of evaluated suspension type porcelain insulators (A, C, E) and ceramic arresters (B, D, F) in the SF chamber (a) and their measurements ((b) and (c), respectively). Respective leakage distances are 285 and 330 mm.

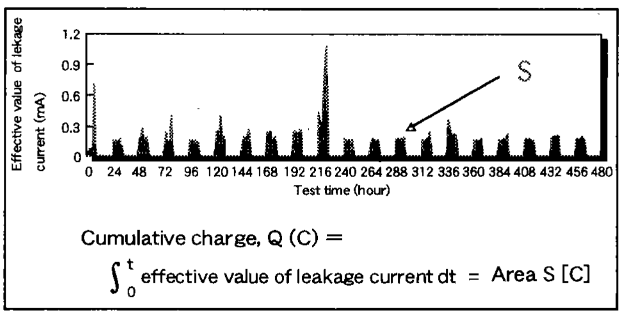

Fig. 2. Definition of cumulative charge for SF test.

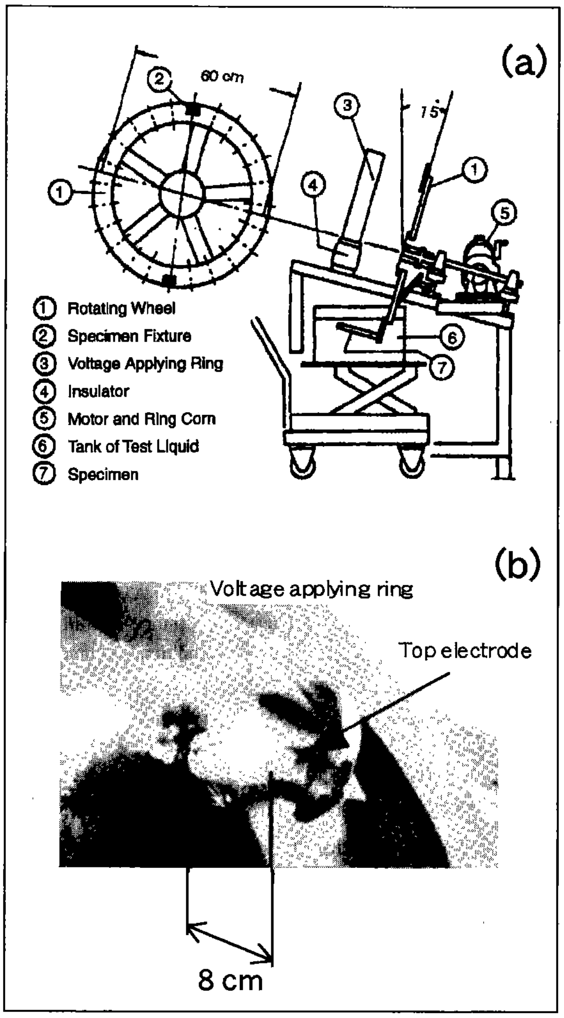

Fig. 3. Experimental details for RWD test. (a) diagram of RWD test, (b) sample arrangement. Sample is just before tracking failure.

2. 2 SF and RWD Tests

An oscillator equipped in a commercial humidifier is used to put fog into the fog chamber. Diameter range of fog generated from commercial oscillators is reported to be ranged from 1 to 20 μm [14]. This range is similar to those of natural fog. In order to quantify the leakage current level, cumulative charges and peak values for leakage current are measured. The definition of cumulative charge is shown in Fig. 2. Six samples are simultaneously tested, so that leakage current on each sample is rotationally acquired. First, wave form of leakage current for 0.5 sec is stored in a digital oscilloscope (HP, 54520A) and calculated effective value and peak value are sent to PC via GPIB interface. Repeating this procedure which takes about 1.2 sec for 5 min, average effective value and highest peak value are obtained. Finally, these are hourly plotted as in Fig. 2 and cumulative charges which are adopted to compare the leakage current level for the samples are calculated. SF tests are conducted under the different ratios of fog-on time to fog-off time and different conductivities of saline water producing fog. Ac 6.0 kV (50 Hz) is

Table 1. Summary of conducted SF and RWD tests for RTV coatings.

	SF test (i)	SF test (ii)	SF test (iii)	RWD test (i)	RWD test (ii)	RWD test (iii)	RWD test (iv)
Substrate and shape	Acrylic rod	BPE rod	Actual ceramic insulators	BPE and CAE rods	BPE rod	BPE rod	BPE rod
Prepared coatings	Uncoated and 0-50% wt ATH filled coatings (0.1- 0.2 mm thickness)	Uncoated and 0-60% wt ATH filled coatings (0.2- 0.3 mm thickness)	Uncoated and 30% wt ATH filled coatings (0.1- 0.2 mm thickness)	Uncoated and unfilled coatings (0.2- 0.3 mm thickness)	Uncoated and unfilled coatings (0.2- 0.3 mm thickness)	Uncoated and 0-60% wt ATH filled coatings (0.2- 0.3 mm thickness)	30% wt ATH filled coatings (0.2- 0.3 mm thickness)
Properties of ATH (particle diameter and coupling treatment)	0.6 μm Untreated	1.0 μm Silane-coupling treated	1.0 μm Silane-coupling treated			1.0 μm Silane-coupling treated	1.0- 55 μm Untreated and silane-coupling
Test conditions (conductivity of saline water, aging time in a cycle of 24 h, applied electric filed)	800 μS/cm 8 h 60 V/mm	1600 μS/cm 12 h 60 V/mm	10000 μS/cm 8 h 21 and 18 V/mm	1330 μS/cm 9-12 h 60 V/mm	1330 μS/cm 9-12 h 60 and 75 V/mm	1330 μS/cm 9-12 h 75 V/mm	1330 μS/cm 9-12 h 75 V/mm
Remarks	Role of ATH level on LC in SF test	Role of ATH level in more severe conditions than those of SF test (i)	Performances of coatings on actual ceramic insulators in SF test	Role of substrate type on LC in RWD test	Role of electric field on LC in RWD test	Role of ATH level on LC in RWD test	Roles of particle size and coupling treatment on LC in RWD test

Notes; BPE: bisphenolic epoxy resin, CAE: cycloaliphatic epoxy resin, ATH: alumina trihydrate filler, LC: leakage current.

applied to cylindrical (rod) plastic substrates coated with RTV of which distance between the electrodes made of stainless steel is 100 mm (60 V/mm electric field). RWD test that is generally called Merry-go-round test is capable of assessing both leakage current characteristic and tracking and erosion resistance [15]. Cylindrical samples fixed on a rotating wheel are continuously turned around, dipped in saline water (1/3 rotation) and then energized (1/2 rotation). Although RWD test needs longer period owing to uncontrolled surface discharges, it has higher accuracy than IEC 60587 IP test [16] and, in addition, can cause a material degradation similar to natural condition [15]. RWD test is prescribed in IEC publication 61302 [17], but this study uses a little scaled down apparatus and employs modified procedures. The diagram of the RWD test apparatus and the sample arrangement with stainless steel electrodes are shown in Fig. 3. The sample dimension is ϕ26 mm$\times$135 mm and the distance between electrodes is 80 mm. Applied voltage is in the range of 4.8-6.0 kV. The conductivity of saline water is 1330 μS/cm at 23 ℃ and adjusted everyday by adding distilled water. Saline water is changed to new one every 100 h. Usual RWD test has no resting period (continuous wetting and energizing), however this study includes resting time for 12-15 hour in a day to emphasize dynamics of material wetting during the resting period. The wheel is fixed with its axis titled 15° to the horizontal and rotates at 3 rpm. Peak leakage current is periodically evaluated. Peak leakage current is highest leakage current value recorded by a digital oscilloscope (HP, 54520A) in 5-10 rotations. After at least 4 h passes from the voltage re-application, it is measured. The trip (end) level is determined at 150 mA_{peak}. SF and RWD tests conducted for evaluating the electrical performances of RTV coatings and assessing the role of material and test parameters on them are summarized in Table 1.

3. Result and Discussion

3. 1 SF Test for Rod Samples Coated with RTV of Different ATH Filler Levels

ATH level near 50% wt is common in outdoor applications of RTV coatings [18]. Wider range of 0-60% wt is employed in this paper for fundamental studies of several roles of ATH filler. Uncoated acrylic and BPE rods and those coated with RTV having 0-60% wt ATH filler are presented to the SF test. ATH filled into RTV coated on the acrylic rods is non-coupling-treated one and its average particle diameter is 0.6 μm. The thickness of RTV coated thereon is adjusted at 0.1-0.2 mm. Coating was completed very neatly on the acrylic rod for high level ATH filled RTV. Leakage current levels for these samples are presented in Fig. 4. The schedule of SF test conducted is that 0-8 h fog and voltage application on, 8-10 h only voltage on, 10-24 h both are off (resting). The conductivity of saline water is 800 μS/cm at 23 ℃ and the fog flow rate is 300 ml/h. These test conditions are one recommended by CIGRE SC15 Japan now preparing the standardization of SF test for outdoor silicone insulation [19]. It is clear that leakage current on the acrylic rod is significantly suppressed by RTV coating. The dependence of leakage current on the level of ATH filler in RTV coatings (0-50% wt) is not observed. Leakage current on RTV-coated BPE rods is also evaluated. Fig. 5 shows BPE rods coated with RTV of different

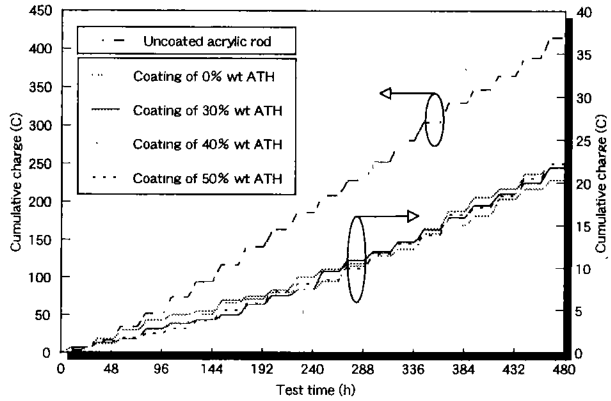

Fig. 4. Cumulative charges of acrylic rods coated with RTVs of different levels of non coupling-treated ATH filler *vs.* salt-fog test duration. Coating thickness is adjusted at 0.1-0.2 mm. The average particle size is 0.6 μm in diameter. Fog flow rate: 300 ml/h, conductivity of saline water: 800 μS/cm, electric field: 60 V/mm, 1 cycle (24 h): 0-8h, fog and voltage application, 8-10 h, only voltage application, 10-24 h, resting.

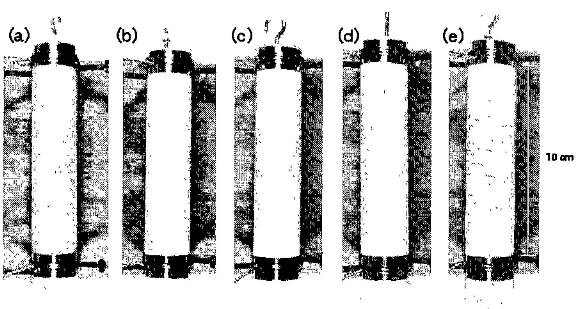

Fig. 5. Photos of BPE rods coated with RTVs of different levels of silane coupling-treated ATH filler. Average filler particle is 1.0 μm in diameter. (a) BPE coated with unfilled RTV, (b) BPE coated with RTV filled with 30% wt ATH, (c) 40% wt ATH, (d) 50% wt ATH, (e) 60% wt ATH.

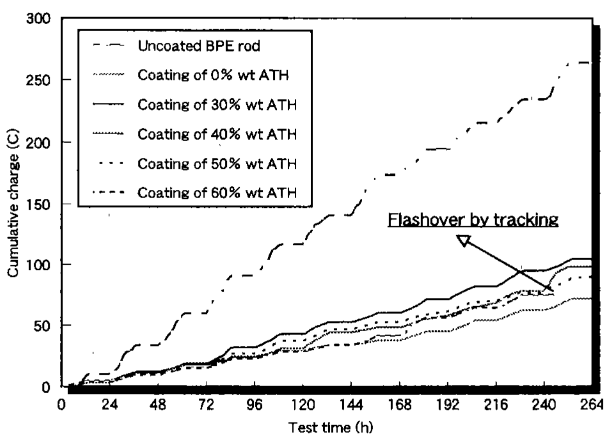

Fig. 6. Cumulative charges of BPE rods coated with RTV of different levels of silane coupling-treated ATH filler *vs.* salt-fog test duration. Coating thickness is adjusted at 0.2-0.3 mm. Average particle size is 1.0 μm in diameter. Fog flow rate: 300 ml/h, conductivity of saline water: 1600 μS/cm, electric field: 60 V/mm, 1 cycle (24 h): 0-12h, fog and voltage application, 12-14 h, only voltage application, 14-24 h, resting.

Fig. 7. A photograph of BPE coated with RTV with 60% wt ATH filler that failed in SF test.

levels of silane coupling-treated ATH filler of which average particle diameter is 1.0 μm. The coating thickness is 0.2-0.3 mm. Although possible trials to adjust the content of carrier solvent were made, cracks appeared on RTV filled with 50 and 60 % wt ATH filler because of solvent evaporation. Plasticizers, usually functional low-molecular-weight silicones, are used for forming without cracking highly filled silicone rubbers [20]. However, this study does not employ placticizers not to increase material parameters affecting electrical performances of RTV coatings and regards cracking as a result of high level ATH loading. The leakage current levels during more severe SF test with the schedule that 0-12 h fog and voltage application on, 12-14 h only voltage on, 14-24 h both are off (resting) is given in Fig. 6. The conductivity of saline water is changed to 1600 μS/cm at 23 ℃, of which level is employed as more severe test condition in CIGRE SC15 Japan [19]. It is found that leakage current on BPE coated with RTV is maintained to be lower level than that of the uncoated. Although uncoated BPE could undergo a development of tracking even permitting a larger leakage current, BPE coated with RTV with 60% wt ATH allowed flashover caused by tracking in the 11th cycle. Failed one is seen in Fig. 7. It is observed that the carbon path develops at the interface between the substrate and RTV coating along cracks formed during its solvent evaporation and vulcanization. This indicates that severe cracking resulting from high level filler addition renders electrolytic solution stored at the interface between the substrate and RTV coating, which can cause serious breakdown accidents. On the other hand, distinct dependence of leakage current on ATH level is not observed in Fig. 6. As also revealed in Fig. 5, it is shown that the suppression magnitude of leakage current on RTV coatings is not strongly dependent on ATH filler level in the range of 0-50% wt under the SF test conditions determined here. Neat coating preparation may be more important than filling high level ATH to obtain substantial performances of RTV coatings.

3. 2 Role of Substrate Type, Filler Level, Filler Particle Size, Silane Coupling Treatment for Filler and Applied Voltage on the Performances of RTV Coatings in the RWD Test

Two types of plastic substrates of BPE and CAE are coated with unfilled RTV. They and uncoated BPE and CAE as reference

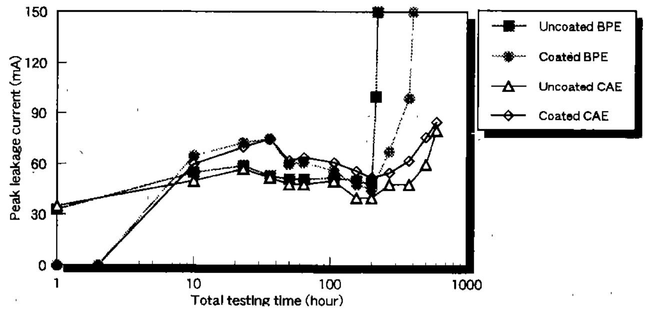

Fig. 8. Relation between peak leakage current on uncoated BPE and CAE and those coated with unfilled RTV. The thickness of RTV coating is 0.2-0.3 mm. Applied voltage is ac 4.8 kV (electric filed: 60 V/mm). The conductivity of saline water is 1330 μ S/cm at 23 ℃. The speed of wheel rotation is 3 rpm. Resting time for 12-15 hour in a day is included to emphasize dynamics of material wetting during the resting period. Peak leakage current presented is an average of three samples. When one or two of three samples failed, its or their peak leakage current is determined at 150 mA_{peak}.

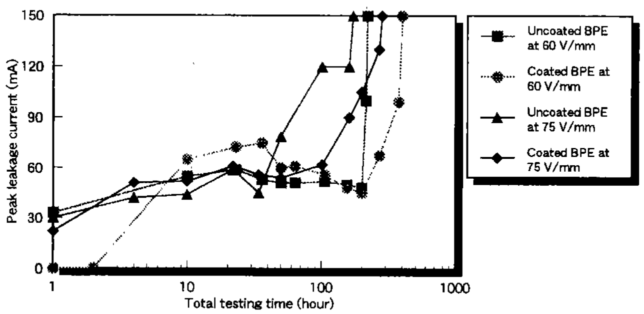

Fig. 9. Peak leakage current on BPE and CAE coated with unfilled RTV during RWD test. The thickness of RTV coating is 0.2-0.3 mm. Applied voltages are ac 4.8 and 6.0 kV (electric filed: 60 and 75 V/mm). The conductivity of saline water is 1330 μ S/cm at 23 ℃. The speed of wheel rotation is 3 rpm. Resting time for 12-15 hour in a day is included to emphasize dynamics of material wetting during the resting period. Peak leakage current presented is an average of three samples. When one or two of three samples failed, its or their peak leakage current is determined at 150 mA_{peak}.

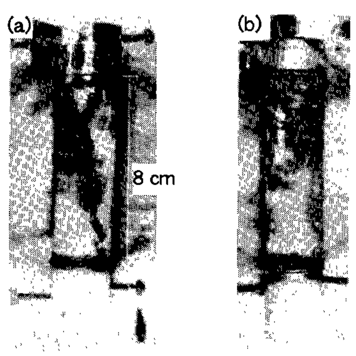

Fig. 10. Photographs of RTV coatings after being aged in RWD test. (a) failed RTV-coated BPE, (b) RTV-coated CAE after being tested for 600 h.

samples are presented to RWD test. Fig. 8 shows the relation between peak leakage current on uncoated BPE and CAE and those coated with unfilled RTV and the total testing time under ac 4.8 kV (*i.e.* 60 V/mm electric field) application. Fig. 9 shows leakage current on uncoated and coated BPE at 4.8 and 6.0 kV (60 and 75 V/mm) to find a role of applied electric field. Peak leakage current presented in the results of RWD test is an average of three samples. When one or two of three samples failed, its or their peak leakage current is determined at 150 mA_{peak}. Hence, if peak leakage current in the RWD results reaches 150 mA_{peak}, it indicates that all the three samples allowed failure. The thickness of all the RTV coatings presented to RWD test is adjusted at 0.2-0.3 mm. It is observed from Figs. 8 and 9 that coated samples induce larger leakage current until they allow a rapid rise leading to failure. Coated and uncoated CAEs shows a similar leakage current levels to those of coated and uncoated BPEs till 200 h. However, BPEs failed by 400 h while CAEs did not even after 600 h. The difference of peak leakage current between uncoated and coated CAEs decreases with the test time. It is also found from Fig. 9 that higher electric field leads either uncoated or coated samples to earlier failure. Fig. 10 shows photos of failed RTV-coated BPE and RTV-coated CAE after being tested for 600 h. At the sections which allow tracking or severe erosion and their vicinities, RTV coatings disappear and the substrates are directly exposed to discharges. This implies that substrate type affects leakage current after RTV coatings are considerably aged, and a final resistance to flashover for RTV-coated insulators is dependent on those of substrates. Fig. 11 shows peak leakage current on BPE coated with RTVs of different ATH filler levels at ac 6.0 kV (electric filed: 75 V/mm). ATH filler is treated with silane coupling agent and its average diameter is 1.0 μ m. 30-40% wt ATH addition gives the longest lifetime to RTV-coated BPEs while excessive addition over 40% wt induces earlier failures. The failure mode of 60% wt filled RTV coating was same as that in SF test. This indicates that high level ATH filler causes cracks and loose adhesion between ceramics and RTV coatings, which could gives detrimental effects. Fig. 12 shows peak leakage current on RTV coatings filled with ATH filler of different particle diameters. The filler level for all the samples is 30% wt and the substrate material is BPE. ATH filler is not treated with silane coupling agent. The result for silane coupling treated ATH is also shown to verify the role of silane coupling agent on the electrical performances. It is observed that leakage current for untreated ATH filler is more suppressed than that for silane coupling treated ATH filler. Silane coupling agents are silane compounds with carbon functional groups (*e.g.*, amino, epoxy and vinyl groups). These could change into harmful silicone oligomers as aging byproducts [20], which induces leakage current and dry-band arcing [21]. Silane coupling agent improves certainly the adhesion between fillers and basic polymers and provides substantial mechanical performance [22, 23], however it induces larger leakage current and more intense dry-band arcing while being energized. However, at present, it needs further analysis on silane coupling agents for ATH to strictly find its influence on electrical performances of RTV coatings. It is also observed that ATH filler of 25 μm in diameter suppresses more leakage current in the early stage of RWD test. The performance in the early stage indicates the resistance to loss of the material hydrophobicity. It is mentioned that hydrophobic surface becomes more hydrophobic after being roughened [24]. The hydrophocity enhanced by an increase in the particle size provides a higher resistance to a formation of water film leading to leakage current and dry-band arcing. However, more larger particles (55 μm) would produce a fragile surface which readily permit leakage current development. ATH particle of 8 μm allows the lowest leakage current in the middle and final stage of RWD test and gives the longest lifetime.

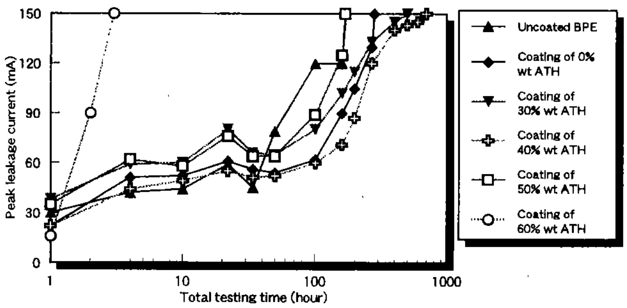

Fig. 11. Peak leakage current on BPE coated with RTVs of different ATH levels during RWD test. ATH is treated with silane coupling agent and its average diameter is 1.0 μm. Thickness of RTV coating is 0.2-0.3 mm. Applied voltage is ac 6.0 kV (electric filed: 75 V/mm). The conductivity of saline water is 1330 μS/cm. The speed of wheel rotation is 3 rpm. Resting time for 12-15 hour in a day is included to emphasize dynamics of material wetting during the resting period. Peak leakage current presented is an average of three samples. When one or two of three samples failed, its or their peak leakage current is determined at 150 mA_{peak}.

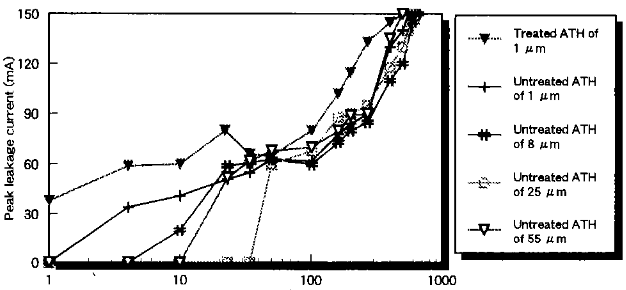

Fig. 12. Peak leakage current on RTV coatings filled with silane coupling treated and untreated ATH filler of different particle diameters. ATH level for all the samples is 30% wt. Thickness of RTV coating is 0.2-0.3 mm. Applied voltage is ac 6.0 kV (electric filed: 75 V/mm). The conductivity of saline water is 1330 μS/cm. The speed of wheel rotation is 3 rpm. Resting time for 12-15 hour in a day is included to emphasize dynamics of material wetting during the resting period. Peak leakage current presented is an average of three samples. When one or two of three samples failed, its or their peak leakage current is determined at 150 mA_{peak}.

In these stages, the surface is completely wet and therefore is subject to continuous and strong dry- band arcing. Hence, smaller particle of 8 μm imparts the most stable surface to suppress leakage current while exposed to dry-band arcing.

3. 3 The Performance of RTV-coated Ceramic Insulators in SF Test

The effectiveness of RTV coatings for the suppression of leakage current on actual ceramic insulators is evaluated. Because RWD test has shown that 30-40% wt is an optimum level for RTV coating in this study and a neat coating which does not make cracks but a good adhesion with ceramic substrates is desired, a little reduced filler level (30% wt) is chosen. The thickness of RTV which is coated on the suspension type porcelain insulators (A, C, E) and the ceramic arresters (B, D, F) by using a fine paint brush is 0.1-0.2 mm. At first, the conductivity of saline water is selected at 1600 μS/cm (23 ℃) and ac 6.0 kV is applied to uncoated suspension insulators and arresters. Ac 6.0 kV produces respectively electric fields of 21 and 18 V/mm of which levels are employed for insulator field designing in heavily or very heavily contaminated areas [25]. However, leakage current accompanied by dry-band arcing is not observed thereon. In order to create a more severe condition inducing dry-band arcing, the conductivity of saline water increases to 10000 μS/cm at 23 ℃ following [26]. Leakage current levels on uncoated and coated insulators during SF test are given in Fig. 13. The schedule of the test is that 0-8 h fog and voltage application on, 8-10 h only voltage on, 10-24 h both are off (resting). It is clear that RTV coatings reduce leakage current levels on the suspension insulators and the arresters. Particularly, leakage current on the arresters is successfully suppressed and dry-band arcing was not allowed at all, because the leakage current level changes little from the first to final cycle. Fig. 14 shows the wetting aspect for uncoated and coated suspension insulators after the last voltage application in 20th cycle of SF test. It is observed that the hydrophobicity of RTV coating is completely maintained. Additionally, an equivalent salt deposit density on the uncoated and coated ceramic insulators after the SF test is measured following the procedure described in [27] (See Table 2). Because saline water on the uncoated insulators can move and drop while that on coated ones forms standing water droplets and makes them stay thereon. Hence, salt is accumulated more on the coated ones and thus ESDD for uncoated insulators is lower than that for coated ones. Mobile low-molecular-weight silicone components diffuse to the deposited salt particles, which encapsulates soluble substances of salt [28]. Hence, although RTV coatings accumulate salt, leakage current thereon is completely suppressed.

3. 4 Performances and Lifetimes of RTV Coatings

Leakage current levels on coated materials in the final stage of

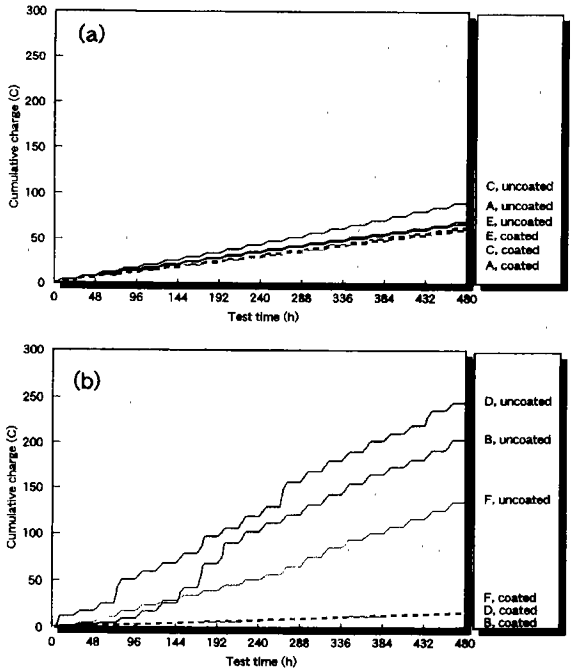

Fig. 13. Cumulative charges of uncoated and coated ceramic insulators A to F during SF test. Coating thickness is adjusted at 0.2-0.3 mm. The level of silane coupling-treated ATH is 30% wt and its average particle size is 1.0 μm in diameter. Fog flow rate: 300 ml/h, conductivity of saline water: 10000 μS/cm, applied voltage: 6.0 kV, 1 cycle (24 h): 0-8h, fog and voltage application, 8-10 h, only voltage application, 10-24 h, resting. (a) suspension type porcelain insulators A, C, E with a 285 mm leakage distance (21 V/mm), (b) ceramic arresters B, D, F with a 330 mm leakage distance (18 V/mm).

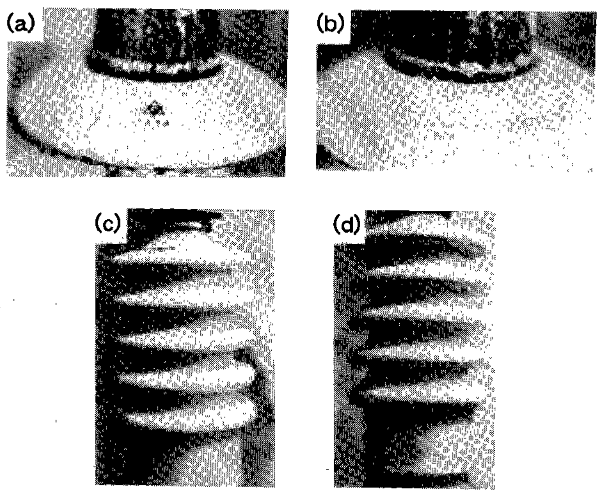

Fig. 14. Wetting aspects for uncoated and coated ceramic insulators after voltage application in 20th cycle of SF test. (a) uncoated suspension insulator, (b) suspension insulator coated with RTV with 30% wt ATH filler, (c) uncoated arrester, (d) arrester coated with RTV with 30% wt ATH filler.

RWD test and their lifetimes are dependent on the substrates' natures. As mentioned in [29], when thinner silicone rubbers

Table 2. Equivalent salt deposit density (ESDD) at the surfaces of uncoated and coated ceramic insulators A to F exposed to SF test having 20 cycles (480 h). For suspension insulators (A, C, E), ESDD at their upper shed area is given. Fog flow rate: 300 ml/h, conductivity of saline water: 10000 μS/cm, applied voltage: 6.0 kV, 1 cycle (24 h): 0-8h, fog and voltage application, 8-10 h, only voltage application, 10-24 h, resting. Unit: mg/cm^2

Upper shed areas of suspension insulators					
Uncoated			Coated		
A	C	E	A	C	E
0.135	0.119	0.052	0.247	0.320	0.309
Whole surface areas of arresters					
Uncoated			Coated		
B	D	F	B	D	F
0.367	0.147	0.323	0.764	0.717	0.620

including less low-molecular-weight silicone components is subjected to moderate dry-band arcing, these produce less harmful cyclic silicone oligomers inducing a formation of carbonaceous tracks. In addition, for thin silicone rubbers, ambient oxygen diffuses readily into the whole of coating, which does not promote tracking but erosion. In the experiments, RTV coatings of which thicknesses are less than 0.3 mm were subject to erosion rather than tracking. RTV coatings on ceramics would not allow flashover resulting from a formation of conductive tracks. Even though, as revealed in [21], high level ATH filler could reduce leakage current levels on silicone rubbers, it may not be mandatory. Poor coating resulting from high level ATH filler causes cracks and loose adhesion between ceramics and RTVs. Electrolytic solution storage at the interfaces between them considerably decreases performances and lifetimes of ceramic insulators. ATH filler level at 30-40% wt seems to be suitable for achieving both the longest lifetime and the best performance. For RTV coatings, neat coating preparation and adhesion between the substrates and coatings are of more importance than tracking and erosion suppression.

4. Conclusion

Leakage current on plastic substrates and actual ceramic insulators coated with RTV in salt-fog and rotating wheel dip tests are evaluated. Roles of ATH filler level, filler particle size, filler surface treatment and type of coating substrates on electrical performances and lifetimes of RTV-coated insulators are investigated. In salt-fog conditions, RTV coatings could successfully suppress leakage current and dry-band arcing on BPE, acrylic and ceramic insulators. The reduction magnitude of leakage current levels is not dependent on ATH filler level in the range of 0-50% wt. When RTV coatings are dipped into saline water and then energized (in rotating wheel dip test), leakage current and dry-band arcing accompanied by it are allowed to develop. ATH filler level, filler particle size, filler surface treatment and type of coating substrates, all the parameters affect electrical performances and lifetimes of RTV-coated insulators. In both the conditions, 60% wt ATH filled RTV coating induces immediate failure because of a poor coating preparation. It is shown that, for RTV coatings, neat coating preparation and adhesion between the substrates and coatings are more important than tracking and erosion suppression by high level ATH addition.

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References

[1] E. A. Cherney, R. Hackam and S. H. Kim, IEEE Trans. Power Delivery, Vol. 6, No. 3, pp. 1177-1181, 1991.
[2] S. H. Kim, E. A. Cherney and R. Hackam, IEEE Trans. Power Delivery, Vol. 6, No. 4, pp. 1549-1556, 1991.
[3] R. S. Gorur, G. G. Karady, A. Jagota, M. Shah and B. C. Furumasu, IEEE Trans. Power Delivery, Vol. 7, No. 2, pp. 713-719, 1992.
[4] S. H. Kim, E. A. Cherney and R. Hackam, IEEE Trans. Elec. Insul., Vol. 27, No. 3, pp. 610-622, 1992.
[5] IEEE Diele. Elec. Insul. Society's Outdoor Service Environment Committee S-32-3, IEEE Trans. Power Delivery, Vol. 10, No. 2, pp. 924-931, 1995.
[6] IEEE Diele. Elec. Insul. Society's Outdoor Service Environment Committee S-32-3, IEEE Trans. Power Delivery, Vol. 11, No. 4, pp. 1881-1887, 1996.
[7] E. A. Cherney and R. S. Gurur, IEEE Trans. Diele. Elec. Insul., Vol. 6, No. 5, pp. 605-611, 1999.
[8] E. A. Cherney, IEEE Ele. Insu. Mag., Vol. 11, No. 6, pp. 8-14, 1995.
[9] S. H. Kim, E. A. Cherney and R. Hackam, IEEE Trans. Power Delivery, Vol. 5, No. 3, pp. 1491-1499, 1990.
[10] S. H. Kim, E. A. Cherney and R. Hackam, IEEE Trans. Elec. Insul., Vol. 27, No. 6, pp. 1065-1072, 1992.
[11] H. Deng, R. Hackam and E. A. Cherney, IEEE Trans. Power Delivery, Vol. 10, No. 2, pp. 1012-1023, 1995.
[12] H. Deng, R. Hackam and E. A. Cherney, IEEE Trans. Power Delivery, Vol. 11, No. 1, pp. 431-441, 1996.
[13] H. Deng and R. Hackam, IEEE Trans. Power Delivery, Vol. 12, No. 2, pp. 857-866, 1997.
[14] M. Nishida, *On the Tracking Deterioration Phenomenon of Organic Insulating Materials and Test Methods*, Doctoral Thesis, Tokyo Institute of Technology, 1984. (in Japanese)
[15] S. M. Gubanski, IEEE Trans. Elec. Insul., Vol. 25, No. 2, pp. 331-340, 1989.
[16] N. Yoshimura, S. Kumagai and B. Du, IEEE Elec. Insul. Magazine, Vol. 13, No. 5, pp. 8-19, 1997.
[17] IEC Publication 61302, *Electrical Insulating Materials-Method to Evaluate the Resistance to Tracking and Erosion, Rotating Wheel Dip Test*, 1995.
[18] R. Hackam, IEEE Trans. Diele. Elec. Insul., Vol. 6, No. 5, pp. 557-585, 1999.
[19] CIGRE SC15 Japan Report, *Current Research Activities on Salt Fog Chamber Test in Japan*, 1999
[20] K. Ito, *Silicone Handbook*, Nikkan Kogyo-shimbunsya, Japan, 1990. (in Japanese)
[21] S. Kumagai and N. Yoshimura, Proc. of the 31st Sympo. Elec. Electro. Insul. Mate. Appl. in Sys., pp. 245-248, 1999. (in Japanese)
[22] Y. Yoshida, T. Higashihara, Y. Nomura, E. Usui and S. Hibi, Trans. IEE of Japan, Vol. 117-A, No. 10, pp. 1004-1012, 1997. (in Japanese)
[23] Y. Yoshida, T. Higashihara, Y. Nomura, E. Usui and S. Hibi, Trans. IEE of Japan, Vol. 117-A, No. 11, pp. 1127-1132, 1997. (in Japanese)
[24] X. Wang and N. Yoshimura, IEEE Trans. Diele. Elec. Insul., Vol. 6, No. 6, pp. 781-791, 1999.
[25] IEC Publication 60815, *Guide for the Selection of Insulators in respect of Polluted Conditions*, 1986.
[26] X. Wang, S. Kumagai and N. Yoshimura, IEEE Trans. Diele. Elec. Insul., Vol. 5, No. 6, pp. 909-916, 1998.
[27] W. A. Chisholm, P. G. Buchan and T. Jarv, IEEE Trans. Power Delivery, Vol. 9, No. 3, pp. 1552-1557, 1994.
[28] J. Kinderberger and M. Kuhl, Proc. 6th ISH, 12.01, 1989.
[29] S. Kumagai and N. Yoshimura, IEEE Trans. Diele. Elec. Insul. (accepted).

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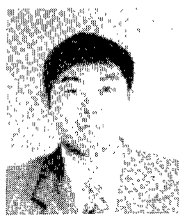

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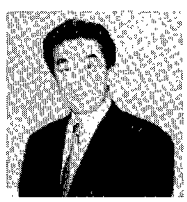

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