Material Screening and Evaluation for Silicone Rubber Insulation with Simple Methods

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The guideline and procedure to select the outdoor silicone rubbers having the best electrical performances from candidates by using slab samples and inclined-plane and salt-fog tests are introduced. Inclined-plane test, which eliminates the material hydrophobic effect, can make evaluations which do not correlate with actual outdoor use to silicone-based materials. However, good understandings on it and the combination with salt-fog test enable an appropriate and valid material selection. It is shown that proposed modified salt-fog method which involves dust deposit has a possibility to produce significant differences among excellent silicone rubbers and to evaluate their performances in considerably severe conditions. The recommended procedure will be helpful for users and manufactures in evaluating and screening silicone rubbers for outdoor insulation.

Keywords: outdoor insulation, silicone rubbers, leakage current, tracking and erosion resistance, salt-fog test, inclined-plane test

1. Introduction

Modern polymeric materials for outdoor high voltage (HV) insulation should possess a compatibility of stable hydrophobicity and sufficient tracking and erosion resistance. Stable hydrophobicity suppresses leakage current even in wet and contaminated conditions, which reduces a probability of flashover and alleviates damages from dry-band arcing involved [1, 2]. Hydrophobicity of silicone rubbers (SIRs) is much more stable than that of polyolefins and, even if reduced, it is able to restore the hydrophobicity in a short dry period. Sufficient tracking and erosion resistance guarantees the material safety in a severe condition that the hydrophobicity is lost and frequent dry-band arcing is allowed. Alumina trihydrate (ATH) filler enhances the tracking and erosion resistance of polymers successfully [3-5]. SIRs containing proper level of ATH filler can achieve the compatibility of high tracking and erosion resistance and stable hydrophobicity. In the future, such the SIRs will be produced by various manufactures and thus they will have a large variety resulting from the differences in formulations, vulcanization systems, filler properties, *etc.* Users have to eliminate defective materials beforehand and choose the best one from candidates with considering a balance among electrical performances, mechanical strengths, cost and several aspects. In such the circumstance, laboratory tests are very useful and reasonable to rank the candidate materials and to estimate, to some extent, the performances in service. Inclined-plane (IP), rotating wheel dip (RWD), salt-fog (SF) tests and those modified are well employed to rank the electrical performances and ensure the material quality [5-8]. They need simply geometric samples, *i.e.* slabs or rods, to avoid any influence by design [9]. A preparation of cylindrical (rod) samples, in particular a neat formation of cylindrical shape without fringes and an adhesion between SIRs and fiber reinforced plastic (FRP) cores, annoys material manufactures. Slab samples are readily prepared from a large sheet which is very productive for material manufactures. This study aims at giving a guideline for material screening and evaluation by using IP and SF tests which are applicable to slab samples. Roles of material parameters such as types of basic polymers and filler properties on electrical performances are not the subjects of this paper.

2. Test methods

Leakage current allowed on the hydrophobicity-lost material surface causes dry-band arcing, leading to tracking and erosion. The hydrophobicity of materials is associated with their tracking and erosion resistance. Leakage current suppression resulting from the hydrophobic stability restricts a formation of dry-band arcing and indirectly contributes to the enhancement of their tracking and erosion resistance. However, the hydrophobicity of silicone rubbers can be reduced when they are subjected to strong stresses [11]. IP test is used for evaluating materials' tracking and erosion resistances eliminating their hydrophobic effects. SF test is for mainly evaluating the durability for materials' hydrophobicity and leakage current development. An appropriate material evaluation needs good understandings on the features of these test methods.

2. 1 IP (IEC 587) Test

The detailed setup and procedure of IEC 587 IP test are presented in [10]. The use of non-ionic wetting agent contained in ammonium chloride electrolytic solution certifies the tracking and erosion resistance eliminating the hydrophobic effect of materials. This test is used to secure the quality in the most severe ambient that frequent dry-band arcing occurs on the material. It is shown that ac 4.5 kV is the most effective applied voltage level to accelerate the development of tracking and erosion for SIRs [12]. Even for SIRs having stable hydrophobicity which prevents a formation of dry-band arcing of a source of tracking and erosion, they should possess sufficient tracking and erosion resistance which is dependent on the requirement level of users. That is because the hydrophobicity of SIRs cannot be always maintained. The materials with poor tracking and erosion resistance while the hydrophobicity is lost are flunked at this test.

2. 2 SF Test

After ensuring the material safety in the worst case that the material hydrophobicity is lost, the leakage current suppression ability, *i.e.* hydrophobicity stability, in fog condition is to be evaluated. Leakage current levels during SF test are indicative of the stability of material hydrophobicity, because hydrophobic surface prevents electrolytic solution dropped thereon from ambient fog from transforming into film leading to leakage current and dry-band arcing. Resting or dry time (without fog input) should be included to reflect the self-restoration ability of the hydrophobicity of SIRs and to ease the operation and guard for this test. It is adequate to conduct the test following a daily schedule that 0-8 h fog and voltage application on, 8-10 h only voltage on and 10-24 h both are off (resting). Leakage current on polymeric materials in salt-fog condition is very sensitive to their surface wetting level. In the early stage of this test, most polymer surfaces resist being wetted because of their inherent low surface free energies and allow extremely low leakage current. With the test duration, the polymer surfaces gradually transfer to wet and allow leakage current to develop. The resistance to leakage current development and allowed leakage current level are one of significant material natures. Fig. 1 shows the diagram and appearance of SF test for this study. Slab (120×50×3.9-6.0 mm^3) samples are used. The distances between electrodes made of stainless steel for slab samples is 80 mm. Ac 4.8 kV is applied to them to produce average 60 V_{rms}/mm electric field. An oscillator equipped in a commercial humidifier is used to put fog into the chamber. 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

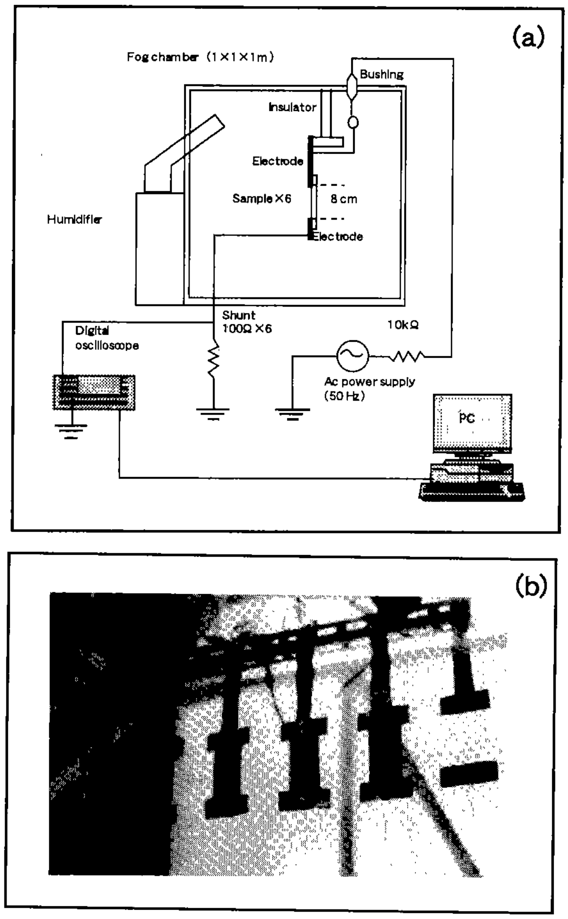

Fig. 1. Experimental details for SF test. (a) diagram of SF test equipment, (b) sample arrangement.

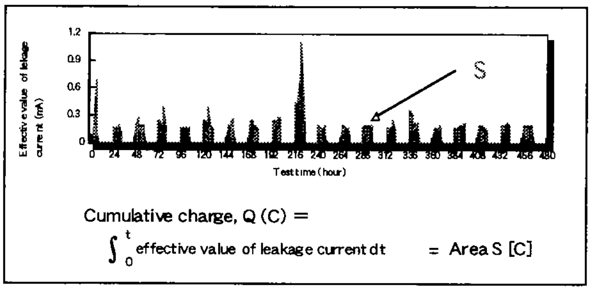

Fig. 2. Definition of cumulative charge of SF test.

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. These are hourly plotted as in Fig 2. Judging from the cumulative charges at the end of 20th cycle [13, 14], the best sample material can be selected. If it is difficult to select best material based on the SF test result, modified SF test involving with dust deposit to create more severe environments is to be done.

2. 3 Modified SF Test

Deposit of non-soluble substances derived from hydrophilic inorganic compounds such as SiO_2 and Al_2O_3 and called dust affects to decrease the hydrophobicity of SIRs. Even though SIRs are covered with dust, they can recover the reduced hydrophobicity because of migration of low-molecular-weight (LMW) silicone chains onto the surface of deposited dust [15, 16]. SF test involving with dust deposit can evaluate the ability of hydrophobicity recovery as well as that of hydrophobicity stability. Distilled water containing dust is sprayed toward slab samples to make an increment of 0.1 mg/cm^2 deposit density. Dust deposit is made every cycle just after the stop of voltage application that continues for more 2 h after the stop of salt-fog input. The deposit of first time is made at 24 h before the first stop of voltage application. The kaolin powder (Nacarai Tesque, Inc., Kyoto) is used as dust. SiO_2 or Al_2O_3 powder would be also available. This test enables a distinct evaluation for SIRs which could not be ranked by usual SF test.

3. Test Results and Material Ranking

9 types of room and high temperature vulcanizing SIRs (SIR1-SIR9) are employed as candidate materials. The sample details are presented in Table 1. The best material which has both sufficient tracking and erosion resistance of which level should refer to the user and best ability of leakage current suppression will be selected following suggested procedures.

Table 1. Sample details.

Sample	Basic polymer	Filler*1 (level, %wt)	Supplier
SIR1	A blend of HTV-SIR and EVA	ATH (40)	A
SIR2	HTV-SIR	ATH (25)	B
SIR3	HTV-SIR	ATH (60)	B
SIR4	HTV-SIR	ATH (40)	B
SIR5	HTV-SIR	ATH (30)	C
SIR6	RTV-SIR	No filler	D
SIR7	HTV-SIR	No filler	B
SIR8	HTV-SIR	ATH (50)	B
SIR9	HTV-SIR	ATH (30)	B

Notes, *1: for imparting tracking and erosion resistance, HTV-SIR: high temperature vulcanizing silicone rubber, EVA: ethylene vinyl acetate rubber, ATH: alumina trihydrate, RTV-SIR: room temperature vulcanizing silicone rubber.

3. 1 IP Test Result

9 SIR samples are presented to IP test. Applied voltage is ac 4.5 kV of which level is most effective to cause tracking and erosion. IP test is carried out to exclude samples having insufficient tracking and erosion resistance. Users have to determine the passing line taking conditions of application sites and several situations into account. If the material is used in very heavy contaminated areas or arterial power lines, users need to set up the passing line highly. 4-7 samples are given to IP test for each material. A success or not is determined by the shortest time to failure of each sample. Test result is shown in Fig. 3. It is observed that SIRs3 and 8 have excellent tracking and erosion resistances. These samples can pass without argument. SIR1 which allows only one failure (around 300 min) in four tests seems to be on acceptable line. The shortest time to failure for SIRs2, 4, 5, 6, 7 and 9 is less than 100 min. As an example, we determine the passing line at the shortest time to failure 100 min. Hence, SIRs1, 3 and 8 are allowed to be forwarded to the SF test. Passing line at the shortest time to failure > 360 min would be available if users desire it considering several aspects.

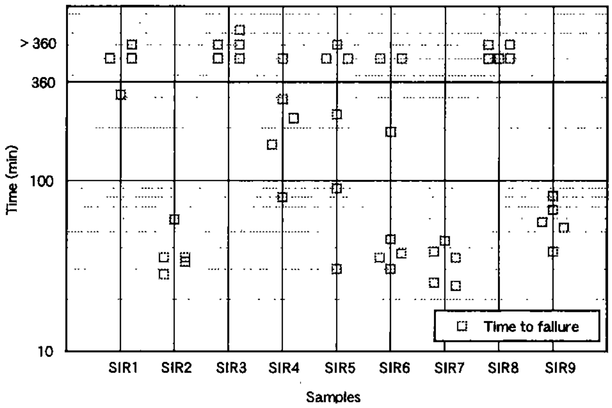

Fig. 3. IP test result for selecting the best SIR materials from 9 candidates. The conductivity of electrolyte is 2400 µS/cm at 23 °C. Applied voltage of 4.5 kV is fixed during the test. Flow rate of electrolyte is 0.6 ml/min. The test is stopped when it passes 6 h or failure takes place. Failure is defined as track develops over 25 mm.

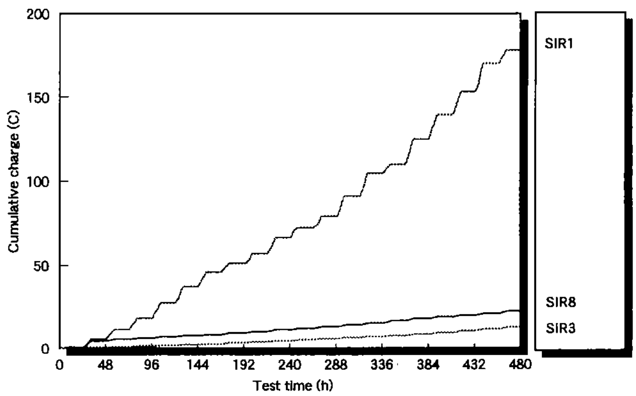

Fig. 4. SF test result for SIRs that have passed IP test. Fog flow rate: 300 ml/h, conductivity of saline water: 1600 μ S/cm, electric field: 60 V_{rms}/mm, 1 cycle (24 h): 0-8h, fog and voltage application, 8-10 h, only voltage application, 10-24 h, resting.

3. 2 SF Test Result

SIRs1, 3 and 8 which have passed the IP tracking and erosion test are then examined by SF test. Fig. 4 shows the cumulative charges of SIRs1, 3 and 8 till the end of 20th cycle. The cumulative charge for SIR1 is much higher than those for the others, indicating that this SIR may allow the hydrophobicity to decrease readily and thus leakage current and dry-band arcing. The best sample can be selected from SIRs3 and 8. Although it is possible to rank as that SIR3 is better than SIR8 from their cumulative charges, significant differences among them seem to be insufficient. For more strict evaluation, SIRs3 and 8 are forwarded to the modified SF test.

3. 3 Modified SF Test Result

Leakage current suppression ability in more severe conditions for SIRs3 and 8, of which cumulative charges in usual SF test are relatively small and in similar level, are evaluated by employing SF test accompanying dust deposit. Dust deposit accelerates the reduction in the hydrophobicity and therefore leakage current development, which creates more significant differences among the samples evaluated excellent in usual SF test. It is found from Fig. 5 that SIR8 shows a smaller cumulative charge than that of SIR3. This implies that SIR3 may allow large leakage current thereon than SIR8 in very dusty environments. The ranking for these 2 SIRs is as that SIR8 is superior to SIR3. This result with that of above SF test without dust deposit suggests SIR8 be selected as the best material from 9 candidates. Of course, the secondary best material of SIR3 is also qualified as second candidates. If the application site of the candidate materials is not so dusty and SIR3 has other merits such as lower cost or better mechanical properties, the choice of SIR3 is also valid. In this study, dust deposit is employed as a secondary stress which affects considerably the performances of materials in service. If one needs to include other stresses such as UV radiation and acid rain, one should do pre or cyclic aging treatments.

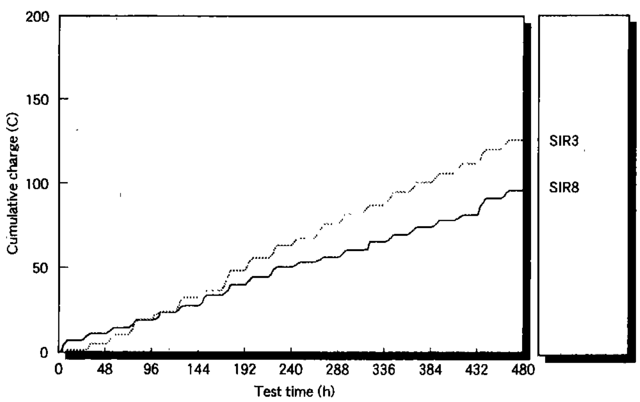

Fig. 5. Modified SF test result for SIRs that have displayed excellent result in ordinal SF test. Fog flow rate: 300 ml/h, conductivity of saline water: 1600 μS/cm, electric field: 60 V_{rms}/mm, 1 cycle (24 h): 0-8h, fog and voltage application, 8-10 h, only voltage application, 10-24 h, resting. Dust of kaolin is deposited to make an increment of 0.1 mg/cm^2 deposit density every cycle just after the stop of voltage application.

4. Conclusion

For selecting the silicone rubber material having the best electrical performances from candidates, the guideline and procedure using slab samples and inclined-plane and salt-fog tests are introduced. It is shown that good understandings on inclined-plane test and its combination with salt-fog test make an appropriate and valid material selection possible. In addition, modified salt-fog method that involves dust deposit is useful to produce significant differences among excellent silicone rubbers and to evaluate their performances in considerably severe conditions.

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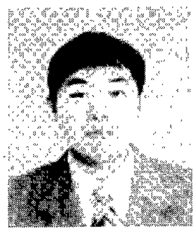

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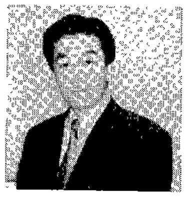

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