Experimental Investigation on Electrical Tracking of Epoxy Resin Compound with Silicon Rubber

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Abstract: The use of polymer materials as electrical insulators on transmission and distribution lines has been increasing such as epoxy resin. Several advantages of using epoxy resin as an insulating material are its low density, better dielectric properties, and epoxy resin has higher volume resistivity than that of the glass and porcelain. However, epoxy resin has some disadvantages when it is used in tropical areas concerning with the humidity, high ultraviolet radiation, acid rain and effects of contaminants. Consequently, insulator surface will be easily damaged due to electrical tracking, which is indicated by the surface tracking. In this paper, the surface tracking on epoxy resin compound with silicon rubber has been investigated. The test was done based on the method of Inclined—Planed Tracking (IPT) IEC 587:1984 with NH_4Cl as contaminant. The test materials used were epoxy resins based on Diglycidyl Ether of Bisphenol A (DGEBA) and Methaphenylene Diamine (MPDA) compound with silicon rubber (SiR) with the dimensions of 50 mm×120 mm and the thickness of 6 mm. The flow rate of contaminant was 0.3 mL/min. The 3.5 kV AC high voltage 50 Hz was applied to the top electrodes. The experimental results show that the contact angle of hydrophobic was affected by compound of silicon rubber. The surface tracking, time to tracking and discharge current were affected by applied voltage, contamination and contact angle. By using micro—cameras, the surface damage was detected. The severest damaged sample surface on a sample had small contact angle. On the other hand, samples with the greatest contact angle needed longer time to have surface damage in the surface discharge. This shows that it is more difficult for large contact angle samples or more hydrophobic to have surface discharge. Epoxy resin compound with silicon rubber has contact angle of hydrophobic greater than epoxy resin without silicon rubber.

Key words: epoxy resin; silicon rubber; tracking; contact angle; discharge current; contaminant
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0 Introduction

Polymer materials have been widely used in the distribution and transmission line for their good dielectric properties, light weight and compact, when compared to the porcelain or glass insulators[1-3]. However, polymer outdoor insulator shows degradation due to climate stresses such as ultraviolet in sunlight, moisture, temperature, humidity and other contaminants so that surface discharge, tracking, and erosion can occur, and also degradation may reduce the performance. This reduction is actually the result of chemical and physical changes taking place on the surface of polymer[4].

Epoxy resin is an important electrical insulating material. It is a thermoplastic polymer in which two components are mixed to eventually form a glassy product at room temperature. Epoxy resins are used in a large number of fields including surface coatings, adhesives, in potting and encapsulation of electronic components, in tooling, for laminates in flooring and are also lightly applied in molding powders and in road surfacing.

Compared with the polyesters, epoxy resins generally have better mechanical properties, and using appropriate hardeners, better heat resistance and chemical resistance (resistance to alkali in particular). The epoxy resins have a dielectric constant about 3.4～5.7, and a dielectric strength about 100～220 kV/cm. Power factors of resin epoxy resins are about 0.008～0.04[5].

When insulators made of epoxy resin are used outdoor, the presence of contaminants on the surface of the insulator becomes a serious problem. Different materials have different contamination performance. Generally non-ceramic insulators perform better than ceramics when new. However, due to aging of polymer housing, this relative difference can change with time at a rate depending on the environment[1].

Leakage current will increase, especially when the insulator surface is wetted by fog, dew or light rain. Leakage current will initiate heat conduction which occurs on the surface of an insulator and finally flashover or insulation breakdown would occur[6].

In this paper, investigation steps on electrical tracking of epoxy resin compound with silicon rubber by using Inclined-Plane Tracking (IPT) method based on IEC 587: 1984 with contaminants NH_4Cl and 3.5 kV is conducted[7]. The test procedure will be explained in this paper and conditions of material surface will be investigated by using micro photo, time to discharge and discharge current analysis. The influences of contact angle of hydrophobic and compound of silicon rubber is also studied.

1 Experimental Set-Up

Polymer insulator (a) suspension and (b) pin-post is shown in Fig. 1. According to Berahim[6], epoxy resin is a hydrophilic material as shown in Fig. 2(a), therefore, in particular, in the tropical area; humidity and rainfall play an important role in accelerating of degradation process on the surface of the insulator. Contamination layer will be formed on the surface of the insulator and it would spread on the surface. Fig. 2(b) shows hydrophobic contact angle from insulating material and Fig. 2(c) shows wetted condition.

1.1 Materials preparation and test sample

The test materials used in this experiment were epoxy resins formed from diglycidil ether of bisphenol—A (DGEBA) and metaphenylene—diamine (MPDA) compound with silicon rubber (SiR). Compositions of the materials are shown in Tab. 1.

Tab. 1 Material compositions of polymeric insulators

Sample	Composition/%		
	DGEBA	MIPDA	SiR
RTV 30	70	30	0
RTV 40	60	40	0
RTV 50	50	50	0
RTV 60	40	60	0
RTV 70	30	70	0
R9S1	45	45	10
R8S2	40	40	20
R7S3	35	35	30
R6S4	30	30	40
R5S5	25	25	50

The samples were prepared in the form of blocks with the dimension of 50 mm×120 mm×6 mm. Test samples should be drilled to place electrodes as illustrated in Fig. 3 (a) and (b).

1.2 Electrodes

All electrodes, fixtures and assembly elements associated with the electrodes, such as screws, shall be made of stainless steel material. The electrode assembly is shown in Fig. 4 (all dimension in mm). The top electrode is shown in Fig. 4(a) and the bottom electrode is shown in Fig. 4(b).

1.3 Contaminant and filter paper

Contaminant used had concentration of 0.1 ± 0.002 % by mass of NH_4Cl (ammonium chloride). These contaminants were flowed on the surface of materials using a peristaltic pump. There were eight layers of filter-papers as a reservoir for the contaminant, which were clamped between the top electrode and the specimen. The approximate dimensions are given in Fig. 5.

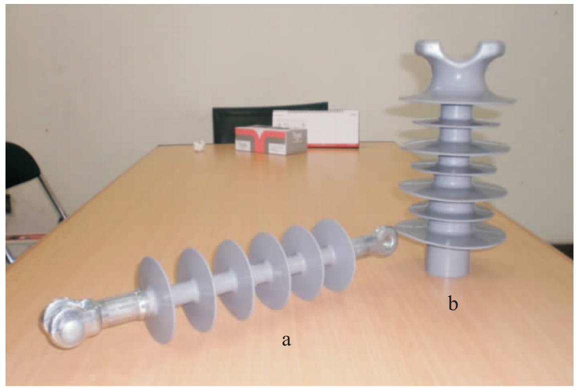
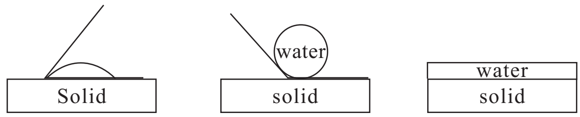


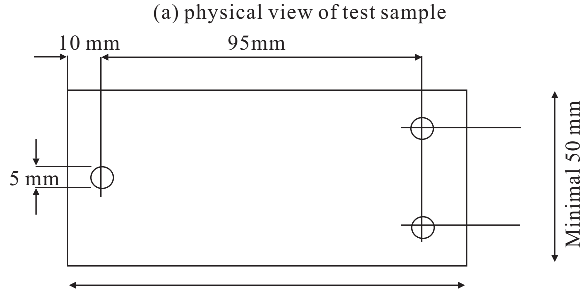
Fig. 1 Polymer insulator (a) suspension and (b) pin-post



(a) 0°<θ<90° (b) 90°<θ<180° (c) θ=0°

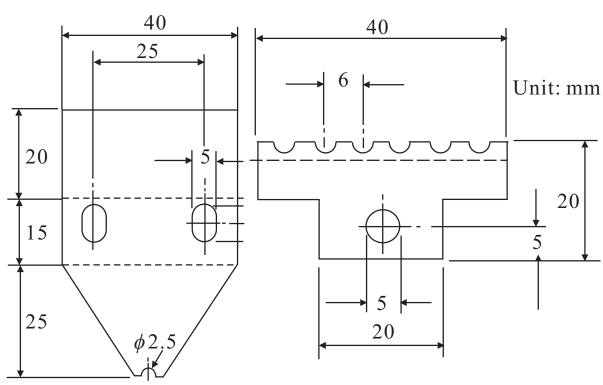
Fig. 2 Contact angle of hydrophobic

(a) physical view of test sample



(b) schema of test sample and its dimension

Fig. 3 Physical view of test sample and schema of test sample and its dimension



(a) top (b) bottom

Fig. 4 Top and bottom of the electrodes

1.4 Test circuit

The system for evaluating the surface tracking of solid polymer insulating materials is shown in Fig. 6. The test is based on IEC 587 standard method and is well known as the Inclined-Plane Tracking (IPT) test. A 50 Hz AC voltage with the amplitude of 3.5 kV was generated from a 5 kVA transformer test. A 22 kΩ resistor was used to limit the current flowing on the surface of the material in the event of discharge. Peristaltic pump was used to drain the solution of contaminants. In this test, the constant voltage method was used, and the time to start tracking was also determined.

All the high voltage equipment was properly grounded for safety purpose. Surface tracking was monitored by measuring the surface leakage current (LC) that flows on the material surface. Test voltage, contaminant flow rabe and series resistor are shown in Tab. 2.

Discharge current will be read and recorded by Oscilloscope in time of discharge on the surface of the material. Measurement data in the form of discharge current and discharge time of the first occurrence are then stored and will be used to analyze the surface condition and the effect of contaminants on the electrical tracking processes in the surface of insulation. The arrangement of electrode, filter paper and sample is shown in Fig. 7.

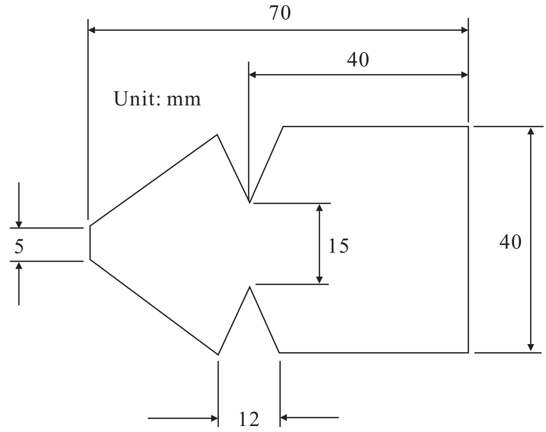


Fig. 5 Filter paper (eight sheets requested for each top electrode)

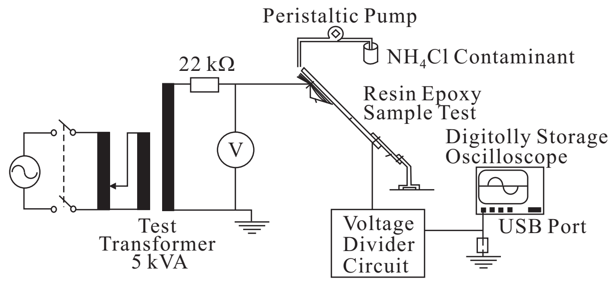


Fig. 6 Schematic diagrams for this test

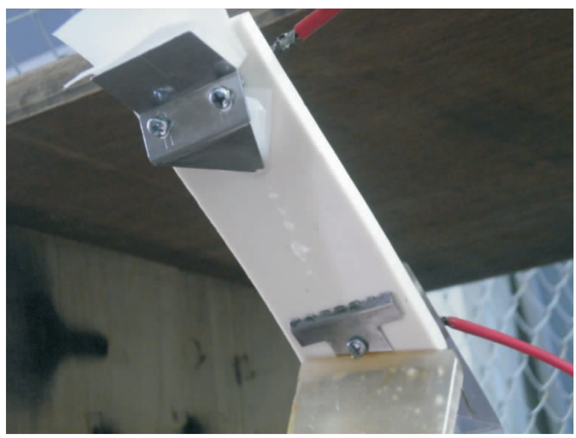


Fig. 7 Arrangement of electrode, filter paper and sample

2 Results and Discussion

2.1 Contact angle of hydrophobic

Contact angle measurement on an insulating material was conducted to determine the surface properties of materials (hydrophobic or hydrophilic). Hydrophobicity is a characteristic of insulating materials. In polluted conditions, the material is still able to resist water that falls onto the surface as shown in Fig. 2(b). Hydrophobic properties are useful for outdoor insulator because in wet or humid conditions, water continuously flowing between the tip-tip of an insulator will be formed and the surface conductivity of insulators will remain low, resulting in very small leakage current.

Conbact angle of test samples is shown in Fig. 8. Measurements of angle contact were carried out on samples of epoxy resin without and with silicon rubber. Measurement results are shown in Fig. 9.

For contact angles smaller than 90°, the material is wet or hydrophilic, otherwise the material is called the hydrophobic or water-repellent. Based on Fig. 9, we know that all samples have contact angles smaller than 90° ($\theta<90°$) which indicates that all samples are hydrophilic.

2.2 Leakage current and time to discharge

Fig. 10 shows the first discharge occurred on the surface for each composition. Based on Fig. 10,

Tab. 2 Test voltage, contaminant flow rate and series resistor

Test voltage /kV	Preferred test voltage for method 1/kV	Contaminant flow rate /(mL·min^{-1})	Series resistor's resistance/kΩ
1.0～1.75	—	0.075	1
2.0～2.75	2.5	0.15	10
3.0～3.75	3.5	0.30	22
4.0～4.75	4.5	0.60	33
5.0～6.0	—	0.90	33

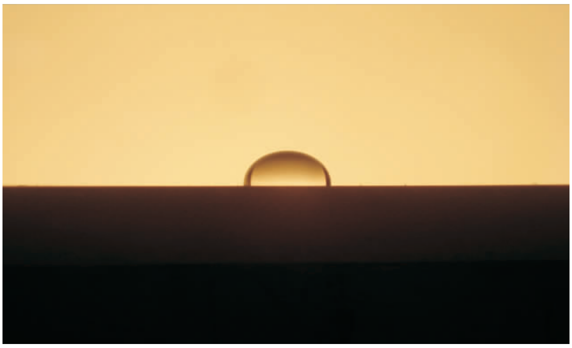


Fig. 8 Contact angle of test samples

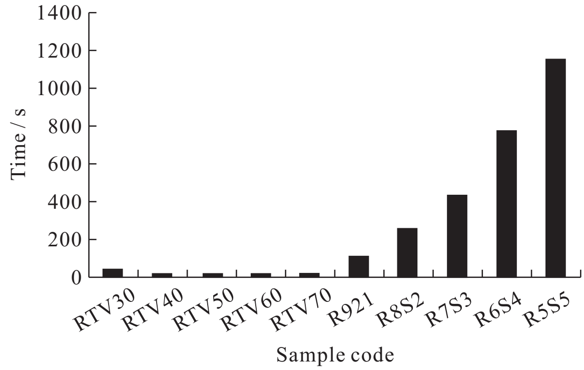


Fig. 10 First time discharge for each sample

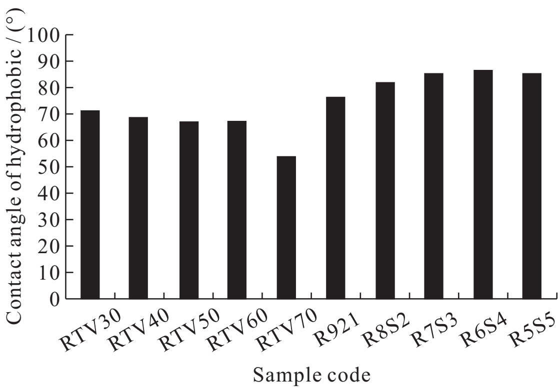


Fig. 9 Characteristics of contact angle of test samples

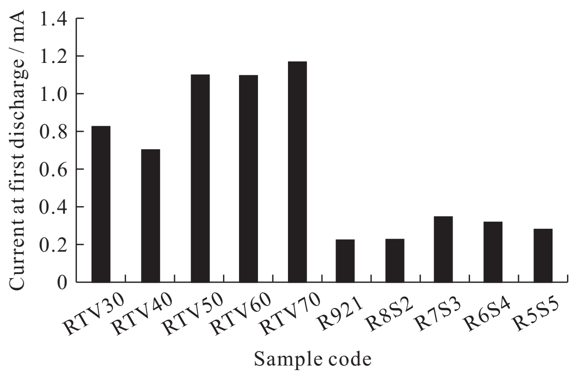


Fig. 11 current at the first discharge

we know that the first discharge is influenced by the composition of the material. The silicon rubber plays an important role in improving the surface tracking on the surface of polymer materials. At a very high composition of silicone rubber (R5S5), the first discharge is more difficult to occur. Contaminant on the surface of the material tends to flow without having wetness, so that the surface degradation and carbon formation is continuously prevented[8].

Fig. 11 shows the first discharge currents in epoxy resin with and without silicone rubber. Based on Fig. 11, the first discharge currents in epoxy resin without silicone rubber is higher than with silicone rubber.

This indicates that the silicone rubber affect discharge current that occurs in the process of tracking surface.

2.3 Surface conditions and tracking process

Sarathi explained that tracking is a surface-degradation phenomenon that occurs when the contaminants accumulate on the surface of an insulation material[9]. When AC high voltage is applied to the top electrode, leakage current flows in the conductive path formed by the contaminant (between top and bottom electrode). This leakage current causes non-uniform heating of the surface, thereby forming a dry-band zone in the continuous wet film formed by the contaminant flow, resulting in regions with very high resistivity between the edges of the remaining wet film surface.

Electrical tracking on the surface of the material sample is due to heating at the surface of the material at the time when leakage current flows and once the process of erosion. Leakage current on the surface of the material occurs due to the contaminants that flow on the surface material. Nearly the entire surface voltage (the applied voltage) will appear across the dry band.

When the air critical flashover voltage was achieved, carbonization process took place and water vaporization happened. Permanent carbonized path was formed. These processes were continuous and cumulative and finally insulation breakdown happened as shown in Fig. 12.

Surface discharge also happened. Erosion at samples surface was followed by the formation of pattern filament which produced the electrical treeing.

Kim et. al. explained that dry — band arcing accelerates the loss of hydrophobicity and degrades the surface of the insulation material[10]. The high temperature of the arc in the gap as well as the high temperature attributed to the possible reaction of HN_4Cl with the polymeric material is considered to be responsible for erosion of material followed by the tracking process. Sometimes the arc burning across the gap is extinguished by the flow of contaminants and the entire process detailed above restarts. However, over a period of time, accumu-

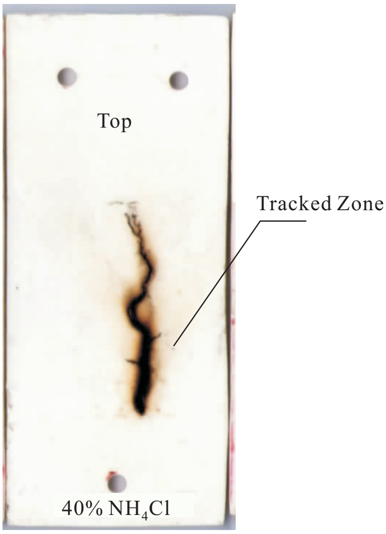


Fig. 12 Tracking formed zone

lation of the contaminants in the gap permits more current to flow in the conductive path formed by the contaminant at the sample applied voltage. Therefore, the entire process is accelerated so that heavy burning takes place between the electrodes, causing a carbonized path, as shown in Fig. 12. This phase is identified as failure resulting from tracking.

Surface condition and tracking zone for each composition is shown in Fig. 13 and 14, respectively. Fig. 14 shows that the severest damage takes place at epoxy resin RTV70 (DGEBA 30% and MPDA 70%) which has contact angle of 52°. A method to characterize the level of surface damage is necessary to determine the surface degradation of material. One possible solution is the micro—photo method[11-13].

Fig. 14 shows that the variation in silicone rubber composition influences the surface tracking. Surface condition of the sample with silicone rubber composition of 10% seems to be more damage than 50%. This is because the epoxy resin compound with silicone rubber of 50% will improve the surface properties of materials, and thus the leakage current is more difficult to occur. Measurements last for 1440 seconds for each sample.

3 Conclusion

The electrical tracking of epoxy resin compound with different compositions of silicon rubber were investigated by analyzing angle contact of hydrophobic, discharge time and discharge current with the inclined-plane tracking test method. Experimental results show that contact angle of hydrophobic depends on the composition of silicon rubber. Based on the compositions investigated, it is found that 50% of silicon rubber offers the optimum surface tracking and erosion resistance. The

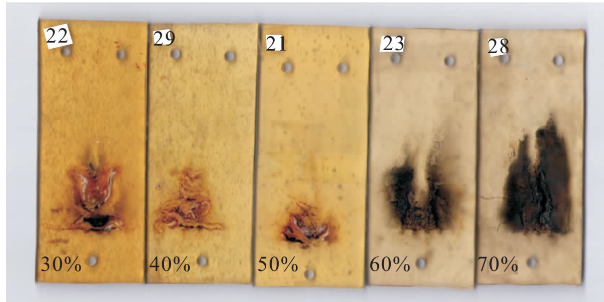


Fig. 13 Surface tracking of epoxy resin without silicon rubber

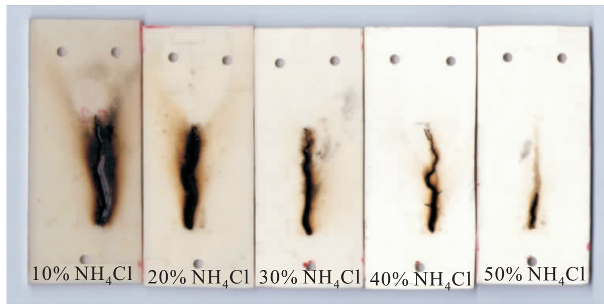


Fig. 14 Surface tracking of epoxy resin with silicon rubber

electrical tracking activity also depends on composition of silicon rubber, which is revealed by measuring the discharge time and discharge current.

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