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Surface Degradation Analysis on Epoxy Resin Polymer Insulation Materials with Bamboo Leaf Ash, Silane, Vinyl Silane Fillers for Electrical Insulators

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ABSTRACT

The porcelain, glass, and polymer materials are insulation materials that are frequently used in air insulation, which is operated at high voltage. Epoxy resin is one of the insulating polymer materials that is utilized since it is superior to that in many ways. However, this insulation material's surface degrades over time owing to external factors, leaving the insulation covered in grime and toxins. This research was conducted on resin epoxy by comparison of MPDA, DGEBA, and filler (bamboo leaf ash and silane) with a percentage value of 10%; 20%; 30%; 40% and 50%, sample size 120 x 50mm, vinyl silane is mixed as a coupling agent of composite materials. Vacuum method to left out void. Based on the IEC 587:1984 standard, the research was performed in the laboratory. Leakage current waveforms, surface degradation driven on by erosion and tracking processes, and tracking duration were all examined in this study to determine their influence on the hydrophobic contact angle value and stoichiometry fluctuation. According to the study's findings, the epoxy resin employed in this study can be classified as hydrophobic and somewhat wetted. Increased silane and bamboo leaf ash filler concentration increased contact angle, which increased surface insulation resistance, making it harder for leakage currents to pass through the surface of an insulating material and delaying aging or degradation. The filler concentration value that provided the best tracking and erosion performance was 40%.

Keywords: Angle of contact, Bamboo leaf ash, Epoxy resin, Hydrophobic, Insulators, Leaky current

1. INTRODUCTION

Polymer materials, especially epoxy resins, are now widely used as insulation for high voltage equipment because they have many advantages compared to other materials. As an external insulator, environmental conditions have quite an effect on the insulating material [1]. The presence of pollutants in the air can cause the surface of the insulator to be coated with precipitated pollutants. When it rains, the pollutants on the insulator's surface will dissolve in the liquid and form a continuous conductive path that may lead in leakage currents. The pollutants on the insulator's surface are dried by the heat produced by the leakage current. Dry bands are being formed as a result of this. Because the electric field distribution in dry bands is stronger than that in other areas, their existence causes a charge discharge into the atmosphere [2]. Longer dry bands will result in flashover, which is the failure of an insulator. The necessity of doing leakage current research in the lab [3],

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particularly on epoxy resin materials containing silane and bamboo leaf ash as fillers, is due to the phenomena of leakage current and the resultant impact that was previously described.

In conducting research on leakage currents on the surface of this insulator, the Inclined-Plane Tracking (IPT) method is used which is regulated in IEC 587:1984 [4]. This approach uses a material sample of a specific size that is placed at a 45-degree angle and is supplied an artificial pollutant liquid with a specific flow, making it perfectly suited to simulate the situation of the external insulator in Indonesia, which suffers high rains. This research is a refinement of previous research using materials with high calcium sand fillers that have not used a composite vacuum system [5][6].

2. RESEARCH METHOD

2.1. Research materials

The materials used in this study are:

a. Diglycidyl ether of bisphenol A (DGEBA) base material in Epoxy resin polymer and MPDA (Metaphenylenediamine) as hardener.
b. Bamboo leaf ash which contains a lot of silica as a filler.
c. *Silane* (Glass Glue).
d. *Vinyl silane*, the coupling agent.
e. *Ammonium Chloride* (NH_4Cl), the pollutant.

Table 1. Composition of the epoxy resin mixture and filler material

CODE	MIXED INGREDIENTS (%)			
	DGEBA	MPDA	SILANE	BAMBOO LEAF ASH
RTV 10	45	45	5	5
RTV 20	40	40	10	10
RTV 30	35	35	15	15
RTV 40	30	30	20	20
RTV 50	25	25	25	25

2.2. Research Equipment

The equipment used in this study includes:

a. A set of tools for printing the test material (glass, mica paper, stirrer, place for mixing the test material)
b. A set of tools for measuring the contact angle (Lamp box with 1000W lamp, 50µl dropper, pollutant holder, glass)
c. A set of tools for testing leakage currents (top electrodes and bottom electrodes made of aluminum (stainless steel), supports, for placing samples that have been clamped by electrodes, filter paper, peristaltic pumps)
d. AC transformer
e. Oscilloscope
f. Composite Vacuum Device
g. Camera

h. A set of computers

2.3. Testing Steps

2.3.1. Research Implementation Procedures

This research was conducted through several stages with standard research procedures according to the research flowchart in Figure 1.

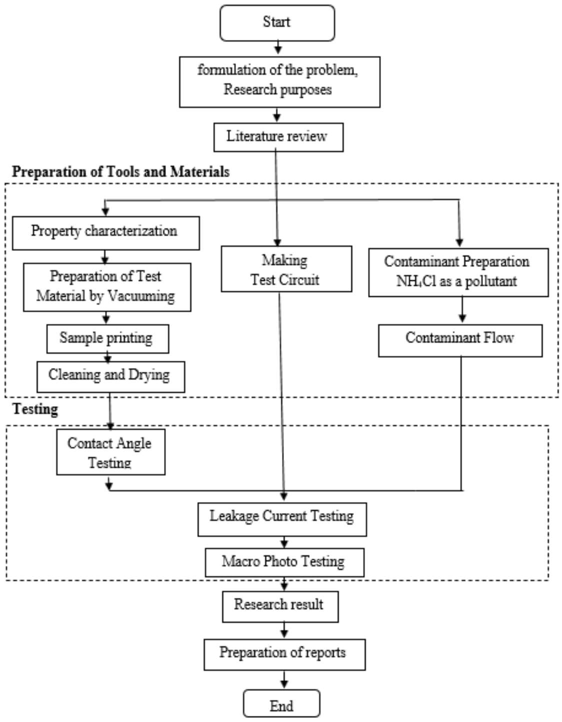

***Figure 1**. Research Flowchart*

2.3.2. Angle of Contact Test

The aim of this contact angle test is to evaluate the test material's surface properties. The important property is hydrophobicity. If the angle obtained is greater, it means that it is likely that the material has hydrophobic properties. The more hydrophobic the surface of the material, the greater the strength of the material to hold water from entering the material [7][8]. The steps for contact angle test are as follows:

a. Set up the sample and turn on the camera so that the sample's surface displays as a straight line on the camera's screen. Drop 50 µl of water. This dripping water is a pollutant that will be used.
b. Turn on the light source so that when the photo is taken, the water point on the surface of the sample is clearly visible.
c. Take a photo with a digital camera, so the results can be directly entered into the computer to get a measurable contact angle.

The following is a picture of the contact angle testing circuit.

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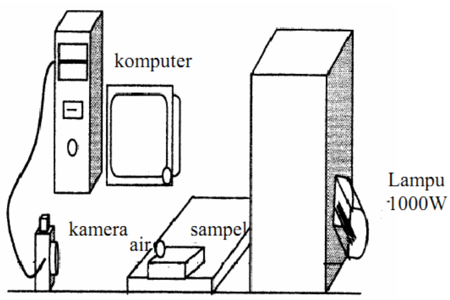

***Figure 2**. Contact angle research series*

Data on the size of the angle for each sample provided as the results of the contact angle test.

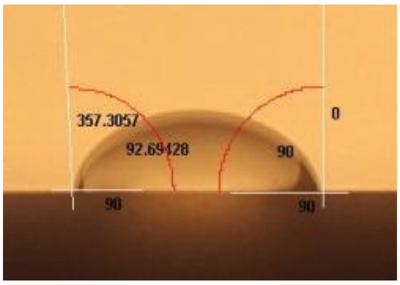

***Figure 3**. Calculation of the sample contact angle*

2.3.3. Leakage Current Testing

Leakage current testing which results in tracking and erosion processes of epoxy resin polymer insulators with contaminated silane fillers is carried out through the following steps:

1. Place the top and bottom electrodes on the sample. On the top electrode, before it was attached to the sample, it was given 8 layers of filter paper. Then put the sample on the support so that the surface of the sample faces down at an angle of 45^0 to the horizontal axis.

***Figure 4**. Placement of electrodes on the test material*

2. Set the pollutant flow rate at 0.3 ml/min, then flow it to the sample through filter paper. The function of using this filter paper is so that there is a uniform flow of

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contaminants from the top electrode to the bottom electrode before voltage is applied. This pollutant flow value corresponds to the application voltage and series resistor according to IEC 587:1984.

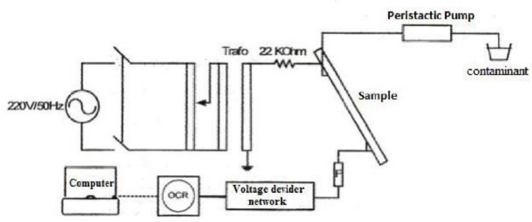

***Figure 5**. Research series diagram*

3. Applying a 3.5 kV voltage to the sample via the top electrode while the bottom electrode is connected to the measuring apparatus. the sample is received from a high voltage generator.
4. Use an oscilloscope to measure the leakage current, then use a voltage divider circuit to overcome the high voltage that enters the oscilloscope.

2.3.4. Surface Degradation Test

The process of measuring the degradation of the surface of the material is carried out using microphotographs which are essentially observations of changes in the aging structure of the test material, with the working procedure as follows:

a. The material is photographed using an ordinary photo, then compared for each concentration.
b. The material is photographed using a macro photo at the part where the conduction pathway occurs
c. The results of the film recording are printed in the form of still images.

3. RESULTS AND DISCUSSION

3.1. Hydrophobic Contact Angle Test

The contact angle of the material surface to the liquid drop is obtained based on direct observations through digital camera shooting which is then stored on a computer. The contact angles on the right and left sides of the test sample were calculated from the shooting results using the Image Pro Plus software.

The results of measurement and calculation of the hydrophobic contact angle of the epoxy silane resin test material for variations in the composition of the filler with NH_4Cl pollutant can be seen in the following table.

Table 2. Contact angle test results

Code	Sample	Contact Angle (°)		
		Left (°)	Right (°)	Best (°)
RTV 10	1	70	74	72
	2	84	84	84
	3	88	91	89,5
RTV 20	1	90	85	87,5

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Code	Sample	Contact Angle (°)		
		Left (°)	Right (°)	Best (°)
	2	91	91	91
	3	91	90	90,5
RTV 30	1	91,5	91	91,25
	2	91,5	92	91,75
	3	91	89	90
RTV 40	1	91	93	92
	2	93	90	91,5
	3	89	76	82,5
RTV 50	1	90	90	90
	2	92	91	91,5
	3	78	65	71,5

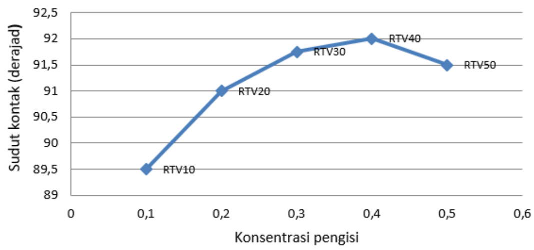

Figure 6*. Graph of relationship between contact angle and filler concentration of epoxy resin composites*

The epoxy resin composite used in this study is partially wetted and hydrophobic, according to the testing results and Figure 6. The contact angle values, which can be classified as partially wetted to hydrophobic, range from 65° to 92°. RTV40 epoxy resin has the largest contact angle. The epoxy resin material's hydrophobic properties come from silane, a filler which contains characteristics that make it reject water.

3.2. Leakage Current Testing

The test material is placed at an angle of 45°. In this study, NH_4Cl pollutants and Parangtritis Beach pollutants flowed at a speed of 0.3 ml/minute on the surface of the test material through an 8-layer filter paper that was clamped between the test material and the top electrode directed downwards. The top electrode is applied to an AC voltage of 3.5 kV.

An oscilloscope image of a voltage wave shows the results of this leakage current test. This voltage waveform's value corresponds to the oscilloscope's input voltage from the voltage divider circuit.. The large input voltage entering the oscilloscope must be overcome using the voltage divider circuit. The following equation can be used to determine the leakage current's value.

$$I_1 = 0{,}0240735\ V_{CF} \quad (1)$$

with : I_1 = Leakage current (A)

V_{CF} = The voltage read on the oscilloscope (V).

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The results of the leakage current test for epoxy resin composites with varying filler concentration values are as follows :

(a) (b)

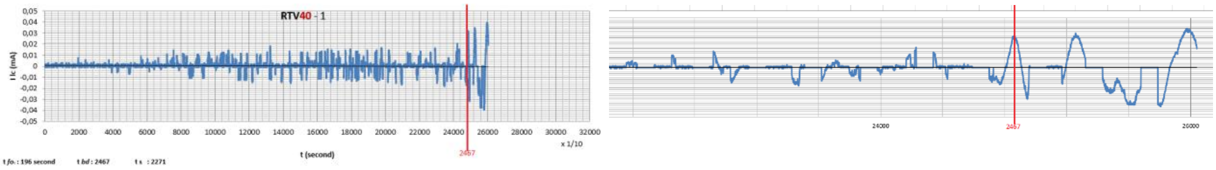

Figure 7*. a) Leakage current test results for the RTV40 resin epoxy composite sample 1. b) Results of 10x magnification range before breakdown*

Based on Figure 7, it can be concluded that a flashover occurs at the 196th second. This discharge is marked by a sudden change in the magnitude of the leakage current. This discharge occurred many times, then an isolation failure occurred which was marked by a sinusoidal wave of leakage current at the 2467th second. This sinusoidal wave indicates that there has been an intact conduction path from the high voltage electrode to the ground electrode.

The same thing also happened to the variations in other concentration values, but the difference was in the frequency and time of occurrence of flash over until breakdown occurred.

Leakage current testing time for NH_4Cl pollutants can be seen in the following table.

Table 3. Surface tracking time (tracking)

Filler Concentration	First flash over (second)	breakdown time (second)	Tracking time (second)
10%	75	1850	1775
	87	1805	1718
	187	2180	1993
20%	50	1208	1158
	400	1750	1350
	310	2105	1795
30%	460	2157	1697
	310	2960	2650
	70	1870	1800
40%	196	2467	2271
	630	2750	2120
	190	2007	1817
50%	55	1800	1745
	125	1300	1175
	94	2117	2023

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The average tracking time of each epoxy resin filler concentration can also be found in the test data. Figure 8 shows the correlation between the average tracking time and the epoxy resin composite concentration value.

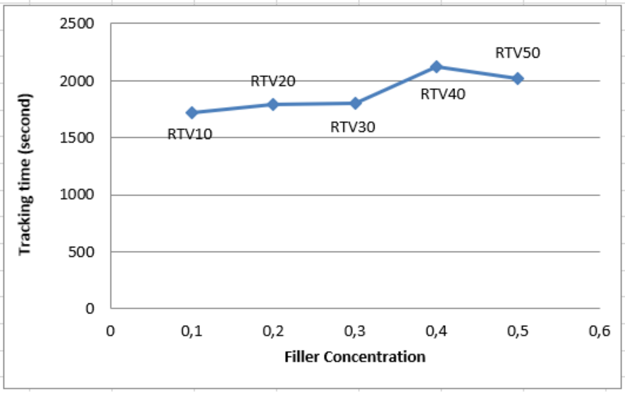
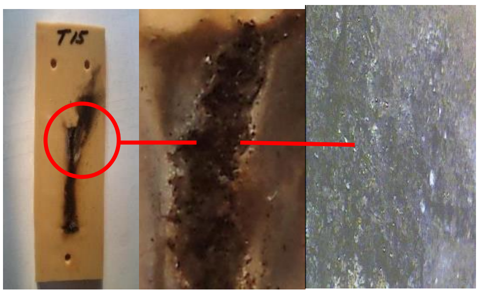


***Figure 8**. Graph of the relationship between tracking time and the concentration of composite fillers*

Figure 8 shows that an increase in the epoxy resin composite's filler content tends to result in an increase in tracking time. This demonstrates that the process of the conduction pathway and carbon pathway on the surface of the insulating material tends to be slower the greater the filler concentration of the epoxy resin composite, which slows down the incidence of surface degradation.

3.3. Surface Degradation Testing

To determine surface degradation in the form of erosion, cracking and calcification, a method is needed to characterize the surface. One of the methods used for this purpose is the macro photo technique.



(a) (b) (c)

***Figure 9**. Photographs (a) without magnification (b) macro10x and (c) macro 30x from the surface of the RTV30 epoxy resin composite sample*

The results of macro photos of the surface of the epoxy resin composite samples used in this study indicate that there has been a structural change on the surface of the epoxy resin insulator composite.

4. CONCLUSION

Based on the data obtained and the results of the data analysis that has been processed, it can be concluded:

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1. An increase in the concentration value of silica bamboo leaf ash, silane and vinyl silane as a filler for epoxy resin composites tends to cause:
   a. The increase in contact angle, the highest contact angle was RTV40 epoxy resin with filler concentration of 20% bamboo leaf ash and 20% silane and the ratio of metaphenylene diamine (MPDA) hardener, diglycidyl ether of bisphenol A (DGEBA) 1:1 with the addition of coupling vinyl silane agent;
   b. Delays the occurrence of insulation failure or makes it difficult for surface leakage currents of epoxy resin insulating materials. An increase in the concentration value of silica bamboo leaf ash and silane as a filler causes an increase in the contact angle, which means an increase in the surface resistance of the insulating material, so that the leakage current does not flow easily on the surface of the insulating material. An increase in the filler concentration of silica and silane bamboo leaf ash will not facilitate flashover which will lead to insulation failure;
   c. Slows down the process of carbon pathways on the surface of the insulating material;
   d. Reducing the damage (degradation) of the surface of the epoxy resin insulating material. The tracking pattern occurs from low voltage to high voltage electrodes. This is because the direction of the actual flow of electrons is from the negative electrode to the positive electrode.
2. The concentration value of silica bamboo leaf ash, silane and vinyl silane as a composite filler will be directly proportional to the tracking time and the magnitude of the contact angle will affect the tracking time, directly proportional to the tracking time.
3. The concentration value of silica bamboo leaf ash, silane and vinyl silane as a filler for epoxy resin composites that have optimal performance against tracking and erosion processes is 40%.

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