Assessment of the Effectiveness of Epoxy Resin Insulation by Combining Silane and Sea Sand with Vinyl Silane as a Coupling Agent and Compatibilized by Polyethylene for Electrical Insulation

Moh Toni Prasetyo[1,2(✉)], Sulistyo[1], S. Nugroho[1], and Syakur[3]

[1] Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang 50275, Indonesia
toniprasetyo@unimus.ac.id

[2] Department of Electrical Engineering, Universitas Muhammadiyah Semarang, Kampus Kedungmundu, Semarang 50254, Indonesia

[3] Department of Electrical Engineering, Faculty of Engineering, Diponegoro University, Semarang 50275, Indonesia
syakur@elektro.undip.ac.id

Abstract. Epoxy resin, which has a number of benefits, is one of the insulating polymers used in high voltage air insulation materials. However, environmental pollution has caused a degradation of the surface. Epoxy resin polymer isolation was the material utilized in this study, along with comparison values for material DGEBA: MPDA at a ratio of 1:1, increased filler, vinyl silane combined as a coupling agent, and PE as a composite material compatibilizer. Vacuum also done to eliminate void in the substance. The research was performed in the laboratory based on the IEC 587 standard, 1984. High-voltage AC generators running at 3.5 kV were connected to high-voltage electrodes. An oscilloscope was connected to the ground electrode to measure the leakage current. The analysis was performed to assess the effect of the variation. The research finds that the composite is hydrophobic and partially wetted. More concentration on filler, causing an increase in the contact angle, delays the aging process on the surface of the insulator. Optimal performance of the filler is obtained when the concentration is 40%.

Keywords: Angle of contact · coupling agent · epoxy resin · hydrophobic · vacuum composite

1 Introduction

When it rains, the pollutants on the surface of the insulator will dissolve and form a continuous conductive layer that will cause current leakage [1]. The occurrence of this current leakage yields heat, which eventually dries out the pollutants on the surface of

T. P. Syawitri et al. (Eds.): MEST 2022, AER 222, pp. 61–72, 2023.
https://doi.org/10.2991/978-94-6463-134-0_7

the insulator. The results are that the ribbon will trigger the payload being released into the air due to the uneven distribution of the electric field on the areas of the surface [2]. If this ribbon formation process continues, it will lead to insulator failure due to flashover. This research was conducted based on the phenomenon caused by current leakage and its impact on the current leakage [3] especially on epoxy resin fabricated by mixing silane and sea sand as the filler, reinforced by a coupling agent and compatibilizer.

Research on leakage current in this insulator was carried out using the inclined-plane tracking (IPT) method in accordance with IEC 587:1984 [4]. In this method, material samples of a certain size are positioned at an angle of 45 degrees and diluted pollutant is given through the stream so that they simulate the situation of external isolators in high rainfall climates in Indonesia [5].

2 Theories

2.1 Insulation Material

One of the natural properties of materials is insulation, where the material will block electrical conduction by blocking voltage conduction so that current leakage, electron transfer, or sparks do not occur in the material [6]. The insulator will physically erode, either partially or completely, which will result in a decrease in insulator performance. Materials that limit the voltage, often referred to as "dielectric strength," will experience wear, and the wear rate will be higher if it operates at high voltages [19]. Dielectric strength is one of the most important properties of an electric material that indicates its ability to insulate and is also very important in determining the quality of an insulator, which will support the entire electrical system [7].

2.2 Epoxy Resin

Epoxy resin is a thermoset polymer, which is a mixture of two substances that will form vitriform at room temperature and has good waterproof and insulating properties. This property is very important for electrical applications, and because of this, this polymer has been used for more than 50 years. Epoxy resin is a good electrical insulator; it also protects electrical components from short circuits, dust, and moisture.

Epoxy resin has the following advantageous characteristics: low viscosity, easy to form, low degradation, good mechanical properties, high insulation ability, and high resistance to chemical reactions.

The epoxy resin utilized in this work is the end product of silane fillers maturing with glass-sticking epoxy diglycidyl ether bisphenol (DGEBA) and metaphenylenediamine (MPDA) which can stick to glass [8].

2.3 Silane as the Materials for the Filler

Silane, or silicon rubber, is a material that can withstand high temperatures and is often used as a cable insulation material and a material that operates at high voltages. Silicon rubber is a relatively new synthetic polymer in application as an electrical insulator

compared to other polymers that are commonly used in such applications, i.e. epoxy resin or polyethylene [7].

Silicon rubber is often compared to ceramic or porcelain, which is more popularly used because it has hydrophobic properties, resulting in low surface conductivity and minimizing current leakage. In addition, silicon rubber has good dielectric properties and is easy to handle and easy to install. Another advantage of silicon rubber is that it is easily corrected by adjusting the filler composition, i.e., silica or calcium sand [9].

2.4 Natural Stone with Silica as Materials for the Filler

Purbalingga is a region in central Java that is abundant in natural stones that contain lots of quartz crystals (SiO2), which are commonly used as filler materials because of their high silica content. Silica is usually used as a glass material in the ceramic industry.

According to the research of UPT and UNDIP, the content of silica dioxide (SiO2) is up to 45% of the total samples used. The addition of natural silicic stone will improve the mechanical properties of the material so that it is not brittle during production [10]. The addition of sand to the filler will also increase the ductility of the material.

2.5 Hydrophobic Contact Angle

The contact angle is the angle between the surface of the test material and where the water drop dripped onto the surface of the test material. Contact angle measurements on certain parts of the insulation material are carried out to determine the surface hydrophobic properties of the material [2]. An assessment of the surface hydrophobicity of the material must be carried out to determine the conditions under which water drops will not remain and cover the surface of the test material so that the test material does not lose its insulating properties and current leakage does not occur [16].

Researchers classify the hydrophobicity of surface materials based on their contact angle. It is classified as hydrophilic when the contact angle is less than 30 degrees. For 30 to 90 degrees, it is partially hydrophobic, and over 90 degrees, it is hydrophobic or classified as water repellent [11–18].

2.6 Vinyl Silane

This material functions as a material binder and also as a coupling agent that binds polymer materials with fillers [10, 11]. The chemical formula for vinyl silane, also known as ethyl silane or vinyl silane, is C2H6Si, or CH2=CH-SiH3. Vinyl silane increases the strength of the material by increasing the adhesive interface of the polymer matrices [12, 15].

2.7 Polyethylene (PE) as the Compatibilizer

Mixture compatibility is the result of the intermolecular chemical interactions of the components in a mixture. Increasing the chemical interactions between components is carried out by adding a compatibilizer, which increases the rate of the mixing process through dispersion. Compatibilizers that are commonly used are polypropylene and polyethylene with a 4% concentration of the total weight of the mixture [12, 13].

Table 1. Mixing composition of composite.

Code	Mixing Composition (%)					
	DGEBA	**MPDA**	***Silane***	**RHA**	***Vinyl Silane***	***Polyetylene***
RTV 10	43,5	43,5	3,5	3,5	4	2
RTV 20	38,5	38,5	8,5	8,5	4	2
RTV 30	33,5	33,5	13,5	13,5	4	2
RTV 40	28,5	28,5	18,5	18,5	4	2
RTV 50	23,5	23,5	23,5	23,5	4	2

2.8 Insulating the Current Leakage and Pollution

The air with pollutants contained in it can cover the outermost part of the insulator's surface with the pollutant substance and form a thin layer. The pollutant layer that has the most influence is the salt layer, which will amplify the leakage current due to the reaction of the electrolyte that will be conducted to the ground through the pillars.

Current leakage caused by pollutant contamination also depends on climate and weather conditions. The wet pollutant layer attached to the insulating material will reduce the resistance of the material, which will result in electric current leakage [14].

The analysis of the leakage current through waveform analysis and the duration of the electrical rejection will significantly affect the overall performance of the insulation material. Therefore, identifying the leaks at an early stage can be used as an indicator that a larger leak is about to occur [17].

3 Materials and Method

3.1 Materials

The materials used in this research are as follow:

1. Hardenend Diglycidyl ether of Bisphenol A (DGEBA) epoxy resin, and hardened Metaphenylenediamine (MPDA)
2. Stick on Glass Silane and silica from sea sand
3. Vinyl Silane as agent of coupling
4. Polyethylene as the compatibiliser
5. NH_4Cl pollutant (Ammonium chloride).

For the coupling agent, vinyl silane was employed in the process of mixing and stirring, and polyethylene was used as the compatibilizer. The mixture was then vacuumed to eliminate the voids (Table 1).

3.2 Equipments

Equipments for this research are:

1. Materials printing test (glass, resin sheet, churn, place mingle the materials test).
2. 1000 W lamp fitting and the lamp, 50 μl pipette straw, a platform to place the pollutant, and a glass for measurement of the angle of contact.
3. Aluminum and stainless steel upper and lower electrodes, sample support for placement of the samples that previously nipped by the electrodes, peristaltic pump, and paper filter for current leaks test.
4. Container with vaccum pump for vaccuum process of the mixture
5. Measurement equipment to perform the measurement of AC transformator, oscilloscope, digital camera and a computer

3.3 Steps of Measurement

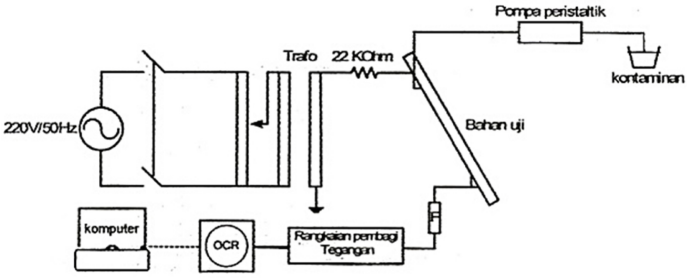
Contact Angle Test
As previously stated, the contact angle test was carried out to test the characteristic of hydrophobicity of the surface. The bigger the contact angle, the more hydrophobic the material. It means that the material will be stronger to hold the liquid substance so that it does not enter the material [8]. The sequence of steps for the contact angle test is as follows:

1. Put the sample on the platform while turning on the camera in such a way that the camera screen can record the surface of the sample.
2. Drippings of pollutant water were counted at 50 l.
3. Turn on the light source so the camera can record the dot irrigation trace clearly on the surface of the sample.
4. The picture taken should be saved directly to the computer. The data on the angle of contact should be recorded for each sample

Leakage Current Test
The current leak test consists of tracking and erosion examinations of the polymer isolator. The steps were as follows:

1. Place the upper and lower electrodes on the sample. Before mounting the upper electrode, put 8 layers of filter paper on the sample. Place the sample on the support in such a way that the part of the sample faces 45 degrees downward.
2. Set the pollutant flow rate at 0,3 ml/minute, then flow the pollutant on the filter paper. Note the flow related to the voltage and resistance in accordance with IEC 587:1984
3. Apply a 3,5 kV voltage on the sample, from high voltage transformator through the upper electrode while electrode of under attributed to a equipments measure.
4. The amount of leakage of the current is measured by using the oscilloscope. To prevent high voltage on the o-scope, use the voltage divider (Fig. 1)

(a)



(b)

Fig. 1. Leakage current test (a) the location of the electrode on the sample or material tested (b) illustrative depiction of the leakage in the current test network

Test on Surface Degradation

To measure the degradation on the material's surface, macro photography was employed. This test is simulating the change in structure caused by ageing on the tested materials. The procedure is done by taking a photo of the conductor ribbons in the materials. The photos will then be compared to observe the degradation for each concentration of the pollutant. Displayed equations are centered and set on a separate line.

4 Results and Discussion

4.1 The Test on Contact-Angle Hidrophobicity

The results of the photography were processed by using the software Image Pro Plus to get the angle of contact on the right and left sides of the tested samples. The results are shown in Fig. 2. It was seen that the characteristics of the resin-epoxy composites used in this research were partially wet and were hydrophobic. The contact angles are ranged from 65° until 91.75°, which can be categorized as partially wetted character to hidophobic (Table 2).

With resin-epoxy RTV40, the contact angle is the maximum. The filler used in epoxy resin, silane, has a water-repellent property and is what gives the substance its hydrophobic properties.

Table 2. The result of the contact angle test

Code	Sample	Contact Angle		
		Left (°)	Right (°)	Best (°)
RTV 10	1	70	74	72
	2	84	84	84
	3	80	90	**85**
RTV 20	1	90	85	87,5
	2	90	90	**90**
	3	91	90	90,5
RTV 30	1	91,5	91	91,25
	2	93	91	**92**
	3	91	89	90
RTV 40	1	93	93	**93**
	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

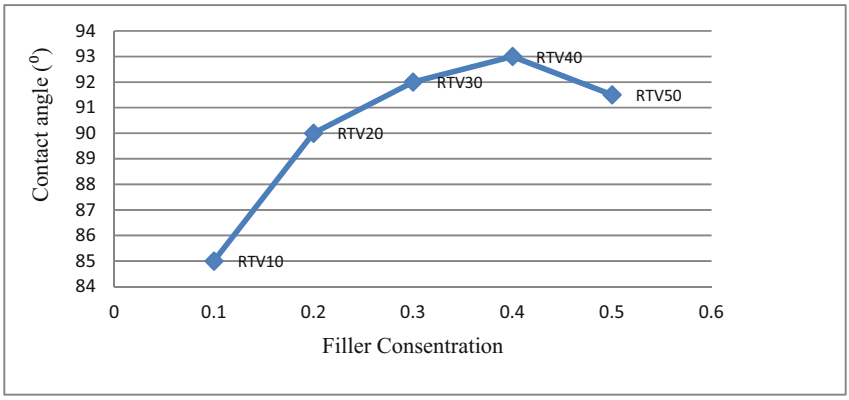
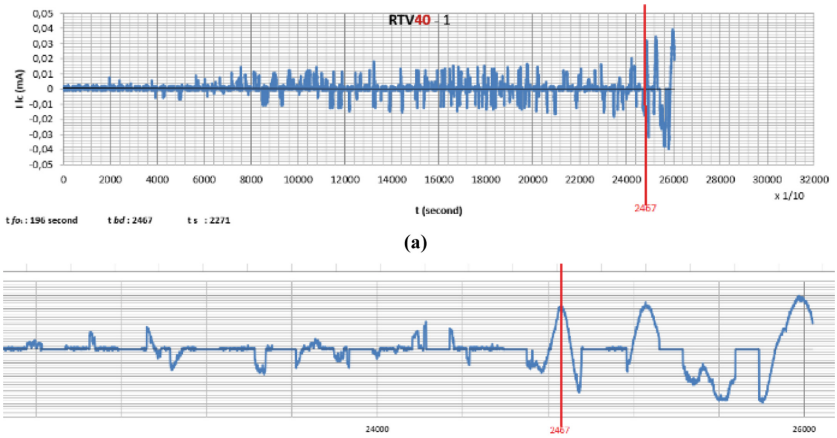


Fig. 2. The relation between contact angle and pollutant concentration

4.2 Leakage Current Test

With an inclination angle of 45°, the NH_4Cl pollutant flows at 0.3 ml per minute onto the surface of the tested materials and through the 8-layer paper filter on the upper electrode to the lower electrode. ac voltage of 3,5 kV is applied at the upper electrode. The result of



(b)

Fig. 3. The result of the test of current leaks on resin-epoxy composite RTV10 sample 3 (a) The moment before breakdown (b) 10x magnification on the range before breakdown

the leakage current test is shown as the wavy waveform in the oscilloscope. The presence of waviness in the voltage represents the value of the voltage divider network.

According to Fig. 3, the discharge occurs at second 196, which indicates the presence of a change in the magnitude of the current leakage. This occurred many times, and when the insulation fails, it is indicated by the sinusoidal current wave at second 2467, indicating the intact conduction band from high voltage on the electrode to the ground.The same events also happened at other concentrations of the pollutant, but at a different frequency until the breakdown occurred (Table 3).

From the result, we can also conclude the mean time tracking of each concentration of resin epoxy filler. The relation between tracking time and the concentration of the composite epoxy resin is shown in Fig. 4. From Fig. 4, it is obvious that increasing the filler concentration of epoxy resin on the composite tends to increase the tracking time. This indicates that the composite filler concentration of epoxy resin will cause the conduction band and carbon band to form at the surface of the insulation materials and tend to delay the degradation of the surface.

4.3 Surface Degradation Test

In assessing the degradation of the erosion on the surface, the characterization of the surface is performed by employing macrophotography.

Figure 5 displays the outcomes of a macrophotograph taken of the epoxy resin composite surface sample used in the test, which reveals how the composite's structure changed.

Table 3. Tracking of Surface Time.

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**

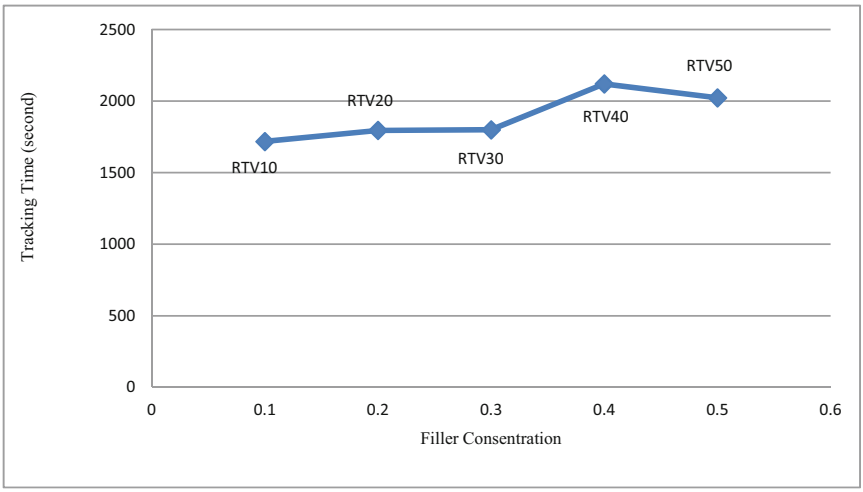
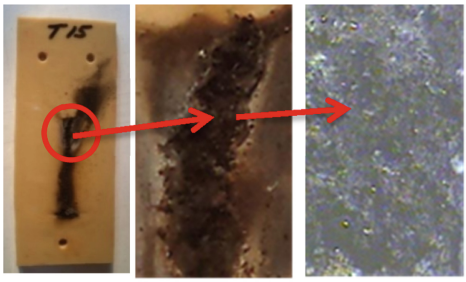


Fig. 4. The relation of tracking time to the composite filler concentration.



(a) (b) (c)

Fig. 5. Results of macrophotography (a) without magnification (b) 10x macro, and (c) 30x macro of the composite surface resin epoxy RTV10 sample.

5 Conclusion

Testing and data analysis provide the following results:

1. Increasing the concentration of sands with high concentratin of silica and *silane* as composite filler with the addition of coupling agent and compatibiliser of resin epoxy tend to cause:

   a) Increasing angle of contact of epoxy resin RTV40 with the 20% filler concentration of sand and 20% silane and comparison of materials of ossifying of *metaphenylene diamine* (elementary MPDA) Basic materials, *diglycidyl ether of bisphenol A* (DGEBA) is 1:1
   b) Lowering the concentration yields the failure of insulation and current leaks. Increasing the sand concentration causing the increase on the contact angle which means higher surface resistance and insulation, thus smaller current leakage. Increasing the sand filler concentration with high calcium and silane prevent the water to penetrate, so that there are no current leakage and no failure in the insulation.
   c) Delaying the process of carbon ribbon formation on the surface of insulation materials.
   d) Surface degradation of epoxy resin tracking patterns was formed due to the direction of electron flow that flows from negative to positive electrodes.

2. High silica and *silane* concentration in sand and the addition of coupling agent and compatibiliser affect the tracking time.
3. At the optimal mixture of high silica and silane, coupling agent, and compatibilizer concentrate, the erosion is 40%.

References

1. Qiu K.: Reliability evaluation of power distribution grids considering the dynamic charging mode of electric buses 2020, Energy Reports 7 (2021) 134–140 (2021)
2. M. Amin, et.al.: Hidrophobicity of Silicone Rubber Used For Outdoor Insulation (An Overview) Advanced Study Center CO. Ltd. (2007)
3. S. Chandrasekar, et.al.: Analysis of Surface Degradation of Silicone Rubber Insulation Due To Tracking under Different Voltage Profiles, Elecr.Eug (2007) 89: 489–50 L (2007)
4. British Standard, BSi: Metode for Evaluating Resistance to Tracking and Erosion of Electrical insulating materials used under severe ambient conditions, IEC 587:1982 (1986)
5. M.T. Prasetyo, Efektifitas Pemanfaatan Pasir Pantai Berkalsium Tinggi Sebagai Material Pengisi Bahan Isolasi Resin Epoksi untuk Isolator Listrik (Media Elektrika,Vol.7 No.2, 2014, Semarang (2014)
6. Ibrahim, M.E. et al.: Partial discharge performance improvement of covered conductor (CC)/ high voltage insulator based electrical distribution systems, Electric Power Systems Research, Volume 202, January 2022, 107601 (2022)
7. A. Eklund, et.al.: Conditioning of Silicone Rubber Insulatiors: Loss and Recovery of Hydrophobicity, 9th ISH, Graz, Austria (1995)
8. Syakur, A. et al.: "An Investigation on Surface Tracking on epoxy resin material" Proceedings of 15th Asian Conference on Electrical Discharge, November, 7–10, Xian Jiaotong University, China (2010)
9. Prasetyo, M.T.: "Efektiftas Pemanfaatan Pasir Pantai Berkalsium Tinggi Sebagai Material Pengisi Bahan Isolasi Resin Epoksi Untuk Isolator Listrik" Jurnal Media Elektrika. ISSN: 1979-7451, Vol.7, No. 2, Semarang (2014)
10. Cui and Kessler: Glass fiber reinforced ROMP-based bio-renewable polymers: Enhancement of the interface with silane coupling agents, Composites Science and Technology 72 (2012) 1264–1272 (2012)
11. Prasetyo D. et al.: Pengaruh Penambahan Coupling Agent Terhadap Kekuatan Mekanik Komposit Polyster cantula Dengan anyaman SeraT 3D Angle Interlock" Jurnal Mekanika Vol.12 No.1, UNS Surakarta (2013)
12. Nilsson, F. et al.: Nanocomposites and polyethylene blends: two potentially synergistic strategies for HVDC insulation materials with ultra-low electrical conductivity, Composites Part B 204 (2021) 108498 (2021)
13. Mayasari H.E. et al.: Pengaruh Kompatibiliser pada Karakteristik Kompon dan Sifat Mekanik Komposit NBR/EPDM, Prosiding Seminar Nasional Kulit, Karet dan Plastik ke-6, Yogyakarta, 25 Oktober 2017 (2017)
14. H. Berahim: "Metodologi Untuk Mengkaji Kinerja Isolasi Polimer Resin Epoksi Silane Sebagai Material Isolator Tegangan Tinggi di Daerah Tropis", Disertasi Fakultas Ilmu Teknik Jurusan Teknik Elektro Universitas Gadjah Mada, 2005 (2005)
15. Kim et al.: Flame and Silane Treatments For Improving The Adhesive Bonding Characteristics Of Aramid/Epoxy Composite, Composite Structures 93 (2011) 2696–2705
16. W. Shaowu, et.al.: 2002, Hydrophobicity Changing of Silicone Rubber Insulators in Service, 21, rue d'artois F-5008, Paris. N (2011)
17. Syakur A. et al.: Morphological Study of Epoxy Resin after Electrical Tracking, Proc. of 20l5 2nd Int. Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), Indonesia, Oct l6–l8th (2015)

18. Kartono: Pemanfaatan Isolasi Resin Epoksi Sebagai Upaya Meningkatkan Kualitas Penyaluran Energi Listrik Ditinjau dari Karakteristik Hidrofobik, Sainteknol Vol. 10 No.1 Juli 2012, Semarang (2012)
19. Tobing B.L.: Peralatan Tegangan Tinggi, Buku ISBN: 9786024860363, Jakarta: Erlangga., 2019 (2019)