# ANALYSIS OF VARIATION OF COAL WASTE FILLING IN PHYSICAL, ELECTRICAL AND MECHANICAL PARAMETERS AS AN EPOXY RESIN ISOLATOR

[1]Denis,[2]Karnoto,[3]Sukiswo

[1] Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia
[2] Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia
[3] Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia

*)E-mail:denisginting@elektro.undip.ac.id

**ABSTRACT**

*The insulator functions to separate two or more conductors and prevent the flow of current between the conducting wires to the tower pole. Many insulators have been developed, including insulators based on epoxy resin. In this study, theaddition of bottom ash to the base material of epoxy resin was analyzed for the value of physical, electrical and mechanical parameters. The test material used is epoxy resin mixed with silicone rubber and bottom ash, each of which has a variation of bottom ash composition with percentages of 10%, 15% and 20%. Parameters analyzed were contact angle testing as physical parameters, leakage current values as electrical parameters and tensile strength and hardness as mechanical parameters. The results of the contact angle test ranged from 1°-89° and had partially wet properties. The results of the leakage current test show that the percentage addition of bottom ash 10% has the smallest leakage current value of 7.985 mA. Meanwhile, from a mechanical point of view, the tensile strength and hardness tests have inverse characteristics,*

**Keywords :** *Bottom ash, contact angle, leakage current, tensile strength, hardness*

## 1. INTRODUCTION

In the developing era, more and more human needs are needed. This is inseparable from the role of electricity which is currently a primary need after clothing, food and shelter. Therefore, reliability in electric power systems must always be improved in line with the development of human needs. The electric power system has three main components, namely the generation system, transmission system and distribution system. Electrical energy starts from the generator which is sent through the transmission and distribution system and ends up in the load. In sending it through the transmission and distribution system there are several important components, one of which is an insulator. Insulators in transmission and distribution networks function to isolate live network conductors from the supporting poles of the network conductors to the ground[1].

The type of insulator used in the transmission and distribution system also influences the reliability of the electric power system, this is because each insulator has several parameters that support its performance, including physical, electrical and mechanical parameters. ParameterThe physical in question is related to the contact angle with respect to the ability of the insulator surface to hold water or commonly referred to as the hydrophobic nature of the insulator. One of the electrical parameters used is the ability of an insulator to separate two live parts so as not to cause leakage currents or short circuits. While the mechanical parameters take a role, namely the ability of the insulatorwithstand the load that will be given to the insulator.

Polymer materials have emerged in recent years and have been developed to replace glass and ceramic materials. This material has advantages in terms of mechanical strength, light weight, thermal properties, volume resistivity and dielectric properties. Light properties in installation and maintenance become easier compared to other materials. Polymer insulators have a lighter weight ratio of 36.7% - 93% compared to porcelain/ceramic insulators. Polymer insulators are water repellent (hydrophobicity) and can also transfer and restore their hydrophobic properties to other pollution layers so that they also become hydrophobic. In humid conditions, wet or raining, this characteristic is very beneficial for outdoor electrical insulators because it does not allow the continuous formation of a layer of water so that the insulator still has low surface conductivity and the leakage current that occurs becomes very small. Polymer materials have emerged in recent years and have been developed to replace glass and ceramic materials. This material has advantages in terms of mechanical strength, light weight, thermal properties, volume resistivity and dielectric properties. Light properties in installation and maintenance become easier compared to other materials. Polymer insulators have a lighter weight ratio of 36.7% - 93% compared to porcelain/ceramic insulators. Polymer insulators are water repellent (hydrophobicity) and can also transfer and restore their hydrophobic properties to other pollution layers so that they also become hydrophobic. In humid, wet or rainy conditions this property is very beneficial for the external electrical insulator because it does not allow the formation of a continuous layer of water continuously so that the insulator still has a low surface conductivity and the leakage current that occurs becomes very small[2].

Epoxy resin is a type of thermoplastic polymer consisting of two components where these two components are mixed at room temperature from a glass product. Epoxy resin has better mechanical properties than polyester. The dielectric constant of epoxy resin is between 3.4 and 5.7, the dielectric strength is between 100 and 220 kV/cm and the power factor is between 0.008 and 0.04[3].

The types of epoxy resins include phenolic, novalac resin, cycloaliphatic resin and bisphenol A. In the first use of outdoor insulation is typeepoxy bisphenol A polymer resin formed by reaction *phenol*and acetone[4].

The mass of the epoxy resin polymer insulating material compared to porcelain and glass is lower so that the mechanical swing of the transmission line conductors is reduced. Epoxy resin is a thermoset type polymer group which is formed from a mixture of two components so that it forms like glass at room temperature which has high water tightness. Epoxy resin polymer insulators do not require large amounts of energy pembuatannya yaitu 20$^o$C-30$^o$C karena mempunyai rapat mass (density) 0.9 2,5 gram/cm3, while glass insulators have a mass density of 2.5 grams/cm3[5]. Elok Faiqoh [6] conducted research on epoxy resin formed into a uniform fin type 20 kV polymer insulator against the influence of surface conditions with variations in test stress. The study used epoxy resin A and hardener B which had a 1:1 ratio, silicon rubber and coal fly ash fillers with a 1:1 composition. The results of this study indicate that the insulating material made meets hydrophobic standards according to STRI Guide I 92/I, leakage current standards according to IEC 950 and THD values according to IEC 519-1992.

The amount of waste along with the times will increase. This is based on the constraints in managing coal combustion waste (LHPB), namely the limited management of LHPB and every day the number of LHPB is increasing. If the utilization of waste is not carried out optimally, it is feared that it will have environmental and social impacts, including the death of plant growth, shortness of breath in humans and so on. At this time, gypsum andFly ash, which is an LHPB, has been widely used, but bottom ash is still minimal, so it continues to accumulate[7].

Hilal Achmad Ghozali [8] conducted research on the effect of using bottom ash on paving blocks with a mixture of shellfish waste as a cement substitution. This research was carried out using a bottom ash composition of 0%, 10%, 20%, 30%, 40% and 50% by weight of cement. The test results showed that the 20% composition had good compressive strength, water absorption and wear resistance.

## 2. METHOD

The research phase carried out is shown in Figure 1 below.

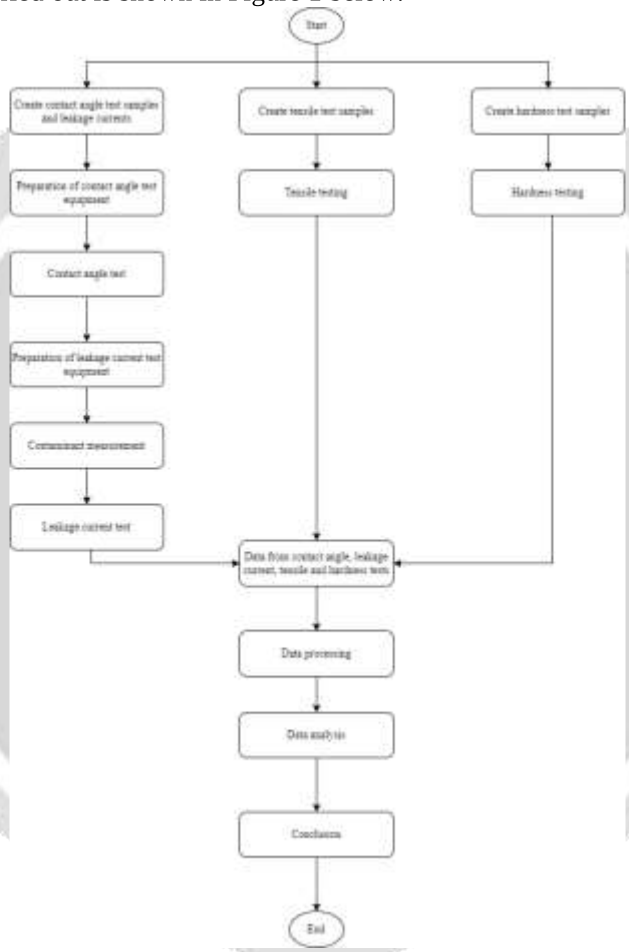


**Fig-1** Research Flowchart

### 2.1. Making Test Samples

2.1 1 Tools and Materials

| | |
|---|---|
| DGEBA resins | Grinding |
| MPDA resins | Drill |
| Silica Rubber | Clamp |

| | |
|---|---|
| Contaminants | Wood |
| Glass Mold | Duct Tape |
| Digital Scales | Mika |
| Plastic Spoon | Scissors |
| Plastic Cups | |
| Whiteboard Marker | |
| Ruler | |

**Table-1** The composition of the test material

| Composition (%) | Mass DGBEA (gram) | Mass MPDA (gram) | Mass *silicone rubber* (gram) | Mass *bottom ash* (gram) | Sample code |
|---|---|---|---|---|---|
| 10 | 40 | 40 | 10 | 10 | 1 |
| 15 | 35 | 35 | 15 | 15 | 2 |
| 20 | 30 | 30 | 20 | 20 | 3 |

2.1.2 Dimensions Test material

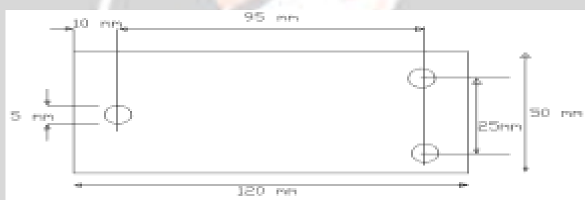


**Fig-2** Dimensions of the sample leakage current test material

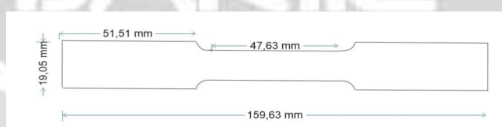


**Fig-3** Dimensions of the tensile sample test material

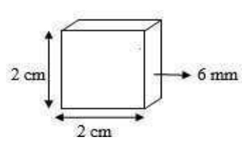


**Fig-4** Dimensions of the sample hardness test material

### 2.1. Contact Angle Testing Equipment

The contact angle is the angle between the surface of the sub$\theta$tance and the tangent to the liquid which determines the measuring quantity of wetting on a surface. The contact angle contains information about hardness, surface roughness and surface energy. Rather the contact angle is also a measure of the contaminated surface.

[9]Angle testing stepscontact is:

1. Prepare equipment for testing such as fiber boxes, incandescent lamps, cameras, tripods and test samples.
2. Furthermore, by using a 60 watt incandescent lamp located inside the fiber box, the surface of the test sample was dripped with DM distilled water using a dropper pipette.
3. Then set the camera focus on the water drops so that the water point focus can be seen clearly. The testing process is carried out three times, namely on the right, left, middle of the test sample.
4. After testing, the contact angle image that has been obtained is measured. Contact angle measurements were carried out using CorelDraw software on a laptop.
5. Contact angle measurements with CorelDraw are carried out carefully so that the angles obtained are appropriate.

**Fig-5** Testing the contact angle

### 2.2. Leakage Current Testing Equipment

Leakage current occurs depending on the pollutant conditions caused by contamination of the surface of the insulating material. If the leakage current is high enough, a continuous discharge will occur which will eventually result in a flashover[10]. The wetting of the contamination layer caused by high humidity and water droplets causes the pollutant to be more conductive so that the surface resistance becomes smaller and then current flowssurface leak. [11] Other things that affect leakage currents are environmental conditions such as different types of contaminant particles or contaminants due to differences in electrolyte ions. [12] The steps for testing the leakage current are as follows.

1. Make a series according to IEC 587: 1984 standard[13].
2. Install the top electrode and bottom electrode on the test sample. Before the top electrode was installed, it was given 8 layers of filter paper. Then put the sample on a 45° support so that the surface of the test sample faces down at an angle of 45° to the horizontal axis.
3. Set the flow rate of the pollutant on the peristaltic pump 0.3 ml/minute and start flowing the pollutant to the sample through the filter paper that has been installed. The filter paper functions as a uniform flow of contaminants from the top electrode to the bottom electrode before voltage is

applied. The pollutant flow value is related to the series resistor and the application voltage according to IEC 587:1984[13].

4. Carry out checks that aim to ensure that pollutants flow right on the surface of the test sample through the top electrode tip to the bottom electrode.
5. Giving a voltage of 3.5 kV to the test sample which is distributed from the high voltage generator to the top electrode and the bottom electrode is connected to the measuring instrument and also to the ground.
6. Measure leakage currents using a leakage current data acquisition device. Using a voltage divider circuit so that the value of the leakage current in the sample can be known.
7. Connect leakage current data acquisition device to computer/laptop via USB cable. By using the software, data leakage current will be

displayed automatically on the computer/laptop screen. Then wait until the sample of the insulator test material forms a flame path and saves the leakage current measurement results on a computer/laptop to be processed.

**Fig-6** Formation of carbon pathways on the surface of the test material

### 2.3. Tensile Strength Testing Equipment

Tensile testing functions to test the strength of the material which is carried out by giving a force load that is characteristicopposite direction. The standard used in this mechanical test is the American Society for Testing Materials (ASTM) E8-E8M-9. [14] The steps in testing the tensile strength are as follows:

1. Prepare testing equipment, namely Universal Testing Machine (UTM).
2. Prepare tensile test specimens.
3. Adjust the type, size and standard of the specimen with the tool.
4. Install the tensile test specimen that has been made.
5. Carry out withdrawals until the tensile test specimen breaks.
6. Let go specimen which already succeed and replace it with another specimen.

**Fig-7** Universal Tes

### 2.4. Hardness Testing Equipment

The steps for testing the hardness of materials include the following:

1. Setting up Vickers Hardness testing equipment..
2. The surface of the test material is given a loading of 1.
3. Run the machine until there is an emphasis on the material, the results of the pressure are in a diagonal shape.
4. Measuring the diagonal of the former pressing the penetrator using a microscope, the measurement results are displayed on the screen of the micro hardness tester.
5. Record the hard value number (HVN) of the test material.

**Fig-8** Hardness Tester

## 3. Results and Analysis

### 3.1. Contact Angle Measurement Results

The results of testing the contact angle of the epoxy resin insulator with variations in the addition of silicone rubber and bottom ash are shown in Figure 9.

**Fig-9** Surface contact angle of the insulator test material

Left contact angle = 80.33°
Right contact angle = 79.85°
The results of contact angle measurements are carried out using the formula:

$$Contact\ angle = \frac{left\ contact\ angle + right\ contact\ angle}{2}$$
$$= \frac{780{,}33 + 78{,}85}{2}$$
$$= 80{,}09$$

**Table-2** The average value of the contact angle measurement results

| Composition | Contact Angle (°) |
|---|---|
| 10% | 77,79 |
| 15% | 78,06 |
| 20% | 72,61 |

After calculating the average value of the contact angle for each variation of the silicone rubber and bottom ash composition, a graph of the relationship between the variation of the silicone rubber and bottom ash composition to the contact angle can be made in Figure 10.

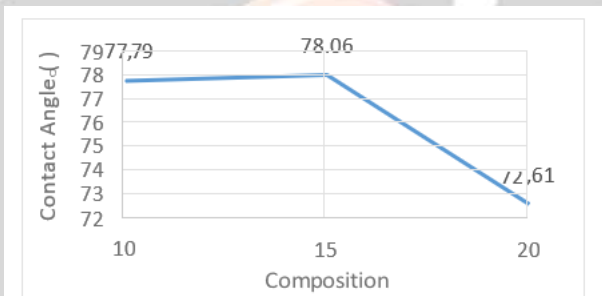


**Chart-10** Graph of the relationship between the contact angle with the addition of silicone rubber and bottom ash

Based on Figure 10, it can be seen that the addition of 15% silicone rubber and bottom ash dripped with distilled water has the largest average contact angle compared to other samples, which is equal to 78.06°.

Graph of the relationship between the contact angle with the addition of silicone rubber and bottom ash is relatively inversely proportional. This is evidenced by the test results that the greater the percentage of silicone rubber and bottom ash, the smaller the surface contact angle. The effect of silicone rubber on the epoxy resin mixture is quite good, but the bottom ash mixture has a lack of air voids. The characteristics of epoxy resin have hydrophilic properties or absorb water which can cause an increase in the value of the leakage current on the surface of the insulator, as well as the characteristics of bottom ash. Meanwhile, silicone rubber has hydrophobic properties so as to minimize the value of the leakage current on the surface of the insulator.

Surface hydrophobicityEpoxy resin material increases when silicone rubber is added. This happens because there are more methyl groups (CH3) in hydrophobic silicone rubber. The methyl group comes from the polyloxane. The hydrophobicity of the epoxy resin surface is influenced by the chemical structure of polysiloxane which is more dominated by the polymethyl functional group (m[CH3]2) which is hydrophobic[15].

Based on Dyah Ika Susilawati's research, it was found that an increase in the percentage of silane fillers causes a greater contact angle which indicates an increase in water-repellent (hydrophobic) properties on the sample surface[16].

### 3.2. Leakage Current Test Results

Leakage current testing is done to analyzeEffect of the addition of silicone rubber bottom ash on the leakage current value of the epoxy resin polymer insulator. The leakage current test uses a voltage variation of 3.5 kV, the test material is placed with a tilt angle of 45º. The test uses pollutants from NH4Cl with a flow rate of 0.3 ml/minute through filter paper that has been clamped between the test material and the upper voltage electrode towards the lower electrode. The results of this leakage current test are shown by the data that appears in the Arduino software through the Arduino spreadsheet which is integrated with the leakage current test tool.

Leakage current testing data is presented in Table 3 below.

**Table-3** Results of leakage current, voltage and tracking time

| Composition | Current (mA) | Voltage (V) | Time(s) |
|---|---|---|---|
| 10% | | 7,985 | 3011 |
| | 599 | | |
| 15% | 10034 | 2875.161 | 699 |
| 20% | 11.69 | 2323576 | 1057 |

Based on Table 3 it can be seen that the composition of silicone rubber and 10% bottom ash has the smallest leakage current value. This is due to the condition of the surrounding air when the test is carried out and the presence of air cavities when stirring for the manufacture of insulator material test samples. Table 3 shows that the greater the addition of the silicone rubber and bottom ash composition, the greater the value of the leakage current that occurs. Silicone rubber has hydrophobic characteristics but bottom ash has the characteristics of absorbing water due to its large amountair voids so that the greater the addition of bottom ash, the greater the value of the resulting leakage current.

### 3.3. Tensile Test Results

Tensile strength aims to determine the strengthinsulators in holding overhead wires in the environment and separating live parts from non-live parts. A good insulator has a large tensile strength value with a small strain value.

In this study, the value of the tensile test was obtained as follow

**Table-4** Tensile and strain test results

| Composition (%) | Strength Tense (Mpa) | Strain (%) |
|---|---|---|
| 10 | 11,395 | 6.76 |
| 15 | 7,256 | 6011 |
| 20 | 5,234 | 9.172 |

Based on Table 4 it can be seen that the tensile strength value of the composition of the addition of silicone rubber and bottom*ash*10% has a tensile strength value of 11.395 Mpa with a strain of 6.76%, the composition of 15% has a tensile strength value of 7.256 Mpa with a strain of 6.011 % and 20% composition has a tensile strength value of 5.234 Mpda with a strain of 9.172%.

From Table 4 above, a graph of the relationship between the value of tensile strength and the composition of the addition of silicone rubber and bottom ash can be graphed in Figure 11 as follows.

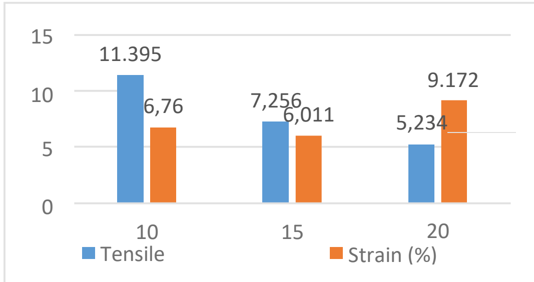


**Fig-11** Graph of the relationship between the composition of silicone rubber and bottom ash with tensile and tensile strength

Based on Figure 11, it can be seen that the highest tensile strength value is owned by a material with a silicone rubber composition and 10% bottom ash, namely 11,395 Mpa. While the lowest tensile strength value is owned by a material with a silicone rubber composition and 20% bottom ash.

Based on Figure 11 it can also be concluded that there is a relationship between tensile strength and composition variation*silicon rubber*and bottom ash is inversely proportional, where the more silicone rubber and bottom ash added, the lower the tensile strength value of the sample. This is due to the flexible mechanical properties of silicon rubber which makes the tensile strength value of the sample decrease when the percentage of silicone rubber increases. So that the best tensile strength is in the composition of the addition of silicone rubber and 10% bottom ash.

### 3.4. Hardness Test Results

The hardness test is intended to support the material's ability to withstand the load of overhead line conductors and to separate two or more conductors with a neutral section. In addition, mechanical testing is also intended to support the performance of insulators in tropical climates. The results of measuring the hardness value of the material can be seen in Table 5.

**Table-5** Surface hardness value of epoxy silicone rubber bottom ash polymer insulator material

| Composition | Right | Middle | Left | Average |
|---|---|---|---|---|
| 10% | 18.43 | 13.6 | 18,8 | 16.94 |
| 15% | 5.77 | 4.93 | 5.17 | 5.28 |
| 20% | 1.2 | 1.7 | 1.3 | 1.4 |

The measurement results in Table 5 can be presented in graphical form as follows.

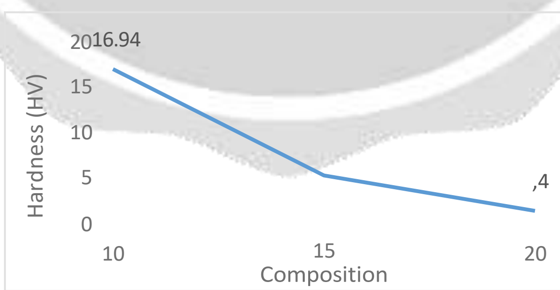


**Fig-12** Graph of material hardness values with variations in the addition of silicone rubber and bottom ash

Based on Figure 12, it was found that the surface hardness of the epoxy resin insulating material with the addition of silicone rubber and bottom ash decreased. The relationship between the hardness of the material and variations in the addition of silicone rubber and bottom ash is inversely proportional. This is due to the flexible mechanical properties of silicone rubber which makes the hardness value of the sample decrease when the percentage of silicone rubber increases. So that the best hardness is in the composition of the addition of silicone rubber and 10% bottom ash.

### 3.5. Determination of Epoxy Resin Materials with the Best Addition of Silicone Rubber and Bottom Ash

The data on contact angle testing, leakage current, tensile strength and hardness that have been obtained are as follows:

**Table-6 Overall data**

| Composition | Corner Contact(°) | Current leaking (mA) | Tensile Strenght (MPa) | Violence (HV) |
|---|---|---|---|---|
| 10% | 77,79 | 7,895 | 11.395 | 16.94 |
| 15% | 78.06 | 10.03 | 7,256 | 5,28 |
| 20% | 72,61 | 11.69 | 5,234 | 1,4 |

The best composition decision is made through the scoring method. The calculation of the results of the scoring performed is as follows.

**Table-7** Calculation of scoring

| Variation | Contact angle | Score | Leakage current (mA) | Score | Tensile strength (Mpa) | Score | Violence (HV) | Score | Total score |
|---|---|---|---|---|---|---|---|---|---|
| 10% | 77,79 | 4 | 7,99 | 6 | 20,85 | 4 | 16,94 | 3 | 17 |
| 15% | 78,06 | 5 | 10,03 | 5 | 17,31 | 3 | 5,28 | 2 | 15 |
| 20% | 72,61 | 3 | 11,69 | 4 | 9,84 | 2 | 1,4 | 1 | 10 |

Based on the score calculation in Table 7, it can be seen that the ingredients with the addition of silicone rubber and 10% bottom ash had the highest total score of 17 points, while the addition of silicone rubber and 20% bottom ash had the lowest total score of 10 points.

Based on the analysis above, it can also be concluded that the best epoxy silicone rubber bottom ash insulator material is the material with the addition of 10% composition, because this composition is better and more stable compared to materials with other compositions. The composition of silicone rubber and 10% bottom ash also got the highest score.

## 4. Conclusion

Based on the research that has been done on the contact angle, leakage current, tensile strength and hardness of the material, it can be concluded:

1. The best contact angle value is owned by the material with 15% bottom ash composition of 78.06°. The lowest leakage current value is owned by a material with a composition of 10% bottom ash of 7,986 mA.
2. The best tensile strength value is owned by a material with a composition of 10% bottom ash of 11,395 MPa. The best material hardness value is owned by a material with a composition of 10% bottom ash of
   16.94 HV.
3. The best epoxy resin insulator with bottom ash filler is a material with the addition of 10% bottom ash, because the composition is better and more stable than the 15% and 20% composition.

## Reference


[1] L. M. K. Amali, “Pollution Intensity Mapping in Transmission Network Isolators,” *Foristek*, vol. 1, no. 1, pp. 51–56, Jan. 2011, Accessed: Dec. 06, 2022. [Online]. Available: https://foristek.fatek.untad.ac.id/index.php/foristek/article/view/82

[2] M. Mustamin and S. Manjang, “Characteristics of High Voltage Polymer Insulators Under Artificial Tropical Climate Stress Accelerated Aging,” *J. Tek. Mesin Sinergi*, vol. 9, no. 1, pp. 23–37, May 2019, doi: 10.31963/SINERGI.V9I1.1065.

[3] A. Syakur and Hermawan, “Leakage current characteristics at different shed of epoxy resin insulator under rain contaminants,” *2014 1st Int. Conf. Inf. Technol. Comput. Electr. Eng. Green Technol. Its Appl. a Better Futur. ICITACEE 2014 - Proc.*, pp. 413–418, Mar. 2015, doi: 10.1109/ICITACEE.2014.7065782.

[4] T. L. Floyd, “Electrical insulation in power systems,” *IEEE Electr. Insul. Mag.*, vol. 14, no. 4, p. 42, 1998, doi: 10.1109/MEI.1998.689278.

[5] D. Ferdiansyah, J. Maurits Nainggolan, and D. Despa, “Characteristics of Partial Discharge in Epoxy Resin Insulation Using Acoustic Emission Method,” *J. Informatics Appl. Electr. Eng.*, pp. 1–6, 2016, Accessed: Dec. 06, 2022. [Online]. Available: http://journal.eng.unila.ac.id/index.php/jitet/article/download/531/583

[6] M. M. Ali, A. Nugroho, and A. Syakur, “Manufacture and Analysis of the Influence of Surface Conditions on the Performance of 20 Kv Polymer Insulators Non-uniform Fin Type With Variation of Test Voltage,” *J. Ilm. Tek. Elektro*, vol. 6, no. 3, pp. 396–403, Nov. 2017, doi: 10.14710/TRANSIENT.V6I3.396-403.

[7] R. M. A. Kinasti and D. N. Notodisuryo, “Utilization of Coal Combustion Waste (Bottom Ash) at Suralaya Power Plant as a Plant Media in an Effort To Reduce Environmental Pollution,” *J. Kaji. Ilmu dan Teknol.*, vol. 6, no. 2, pp. 129–138, Dec. 2017, doi: 10.33322/KILAT.V6I2.129.

[8] H. A. Ghozali, “The Effect of Using Bottom Ash on Paving Blocks with a Mixture of Shellfish Waste As a Cement Substitution,” *Rekayasa Tek. Sipil*, vol. 1, no. 1/REKAT/18, pp. 186–194, 2018, Accessed: Dec. 06, 2022. [Online]. Available: https://jurnalmahasiswa.unesa.ac.id/index.php/23/article/view/22143

[9] A. Syakur and H. Berahim, “Hydrophobic Contact Angle and Surface Degradation of Epoxy Resin Compound with Silicon Rubber and Silica,” *Electr. Electron. Eng.*, vol. 2012, no. 5, pp. 284–291, 2012, doi: 10.5923/j.eee.20120205.07.

[10] E. Kuffel, W. S. Zaengl, and J. Kuffel, *High voltage engineering : fundamentals*, 2nd ed. Butterworth-Heinemann/Newnes, 2000.

[11] Nurlailati, “Analysis of Surface Degradation of Insulating Materials, Epoxy Resin due to Tracing and Erosion Processes,” Elsevier, Yogyakarta, 2010. doi: 10.1016/J.POLYMDEGRADSTAB.2007.01.014.

[12] A. Syakur, “Theory and Partial Experimental Results Discharge,” *BP UNDIP*, 2009, doi: 10.33258/KONFRONTASI2.V7I3.116.

[13] N. Yoshimura, S. Kumagai, and B. Du, “Research in Japan on the tracking phenomenon of electrical insulating materials,” *IEEE Electr. Insul. Mag.*, vol. 13, no. 5, pp. 8–19, Sep. 1997, doi: 10.1109/57.620513.

[14] “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete” Accessed: Dec. 06, 2022. [Online]. Available: https://www.astm.org/standards/c618

[15] A. Syakur and H. Sutanto, “Determination of Hydrophobic Contact Angle of Epoxy Resin Compound Silicon Rubber and Silica,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 190, no. 1, p. 012025, Apr. 2017, doi: 10.1088/1757-899X/190/1/012025.

[16] D. ika Susilawati, H. Hermawan, and A. Syakur, “Surface Leakage Current Analysis of Epoxy Silane Resin Insulating Materials Using the Inclined-Plane Tracking Measurement Method,” *J. Ilm. Tek. Elektro*, pp. 1–7, Jun. 2012.