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Optimization of Mechanical Performance Polymer Insulators SiR Using CFA Waste as Filler

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ABSTRACT

This study investigates the use of coal fly ash as a filler in Room Temperature Vulcanization (RTV) silicone rubber to enhance its mechanical properties. Fly ash, which contains silica, has the potential to improve the strength of the polymer. The research aims to optimize the composition of fly ash in RTV silicone rubber composites using the quadratic regression method, focusing on tensile strength and elongation performance. Tests were conducted according to ASTM D 412 standards for tensile strength and elongation. The results showed that the optimal fly ash composition for tensile strength was 38.11%, resulting in a tensile strength of 0.19 and a Mean Absolute Percentage Error (MAPE) of 13.64%. For elongation, the optimal composition was 14.95%, with an elongation value of 192.094 and a MAPE of 24.75%. This study provides valuable insights into how fly ash can be used to enhance the mechanical properties of RTV silicone rubber composites.

Keywords: *Coal fly ash; Mechanical performance; Optimization; Quadratic regression; RTV silicone rubber*

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ABSTRAK

Penelitian ini mengkaji penggunaan abu terbang batubara sebagai pengisi pada karet silikon tipe Room Temperature Vulcanization (RTV) untuk meningkatkan sifat mekaniknya. Abu terbang yang mengandung silika berpotensi memperkuat polimer. Tujuan penelitian ini adalah mengoptimalkan komposisi abu terbang dalam komposit RTV silikon menggunakan metode regresi kuadrat, dengan fokus pada uji kekuatan tarik dan elongasi. Pengujian dilakukan sesuai dengan standar ASTM D 412 untuk kekuatan tarik dan elongasi. Hasil penelitian menunjukkan komposisi optimal abu terbang untuk kekuatan tarik adalah 38,11%, dengan kekuatan tarik 0,19 dan Mean Absolute Percentage Error (MAPE) sebesar 13,64%. Sedangkan untuk elongasi, komposisi optimal abu terbang adalah 14,95%, dengan nilai elongasi 192,094 dan MAPE sebesar 24,75%. Penelitian ini memberikan wawasan yang berharga mengenai pemanfaatan abu terbang untuk meningkatkan sifat mekanik komposit RTV silikon.

Keywords: *Fly ash batubara; Karet silikon RTV; Kinerja mekanik; Optimasi; Regresi kuadratik*

INTRODUCTION

Most of Indonesia's electricity is generated by steam power plants that use coal as the main fuel. In 2019, Indonesia produced around 8.31 million tons of coal fly ash, and this amount continues to increase annually [1]. The large production of fly ash has a negative environmental impact due to the toxic particles it contains, such as Pb, Cd, As, and Hg, which can contaminate soil and water, affecting living organisms. Currently, coal fly ash management in Indonesia is concerning, as most of it is handled locally, simply spread in open areas (landfills), and compacted with water [2]. Given its potential and environmental impact, this has prompted researchers to explore solutions for effectively utilizing fly ash waste as a viable material [3, 4].

Coal fly ash is classified into different groups based on its caloric value. Regardless of this, fly ash contains several key components from the combustion process, including silica, alumina, iron, calcium, carbon, magnesium oxide, sulfate, phosphate, and others [5-7]. The silica content in various types of coal fly ash is notably high, making it valuable for use in cement products, rubber fillers, and other applications. As shown in Figure 1, a fly ash sample, the nanosilica content in the filler can enhance the tensile strength of polymer materials such as Ethylene Propylene Diene Monomer (EPDM) rubber and silicone rubber (SiR). [8]. In addition to increasing the mechanical properties of polymer materials, nanosilica is also able to increase the dielectric capabilities of epoxy polymer materials [9]. In addition to the benefits of silica contained in coal fly ash, and the large costs required to separate from each of the coal fly ash contents [10].

Coal fly ash has great potential as an industrial rubber filler [11]. Insulators, as key electrical equipment, play a crucial role in the distribution of electrical energy. Currently, polymer-based insulators are gaining popularity due to their advantages over porcelain and glass, particularly their high hydrophobic properties [12], has a lower mass density, is easy to manufacture because it does not require very high temperatures in the manufacturing process, and has a high level of adhesion.

The research titled "Electrical and Mechanical Properties of Fly Ash Filled Silicone Rubber for High Voltage Insulators" demonstrates that adding coal fly ash with a high calorific value can improve the electrical and mechanical properties of polymer silicone rubber insulators. The study compared electrical and mechanical test results of various silicone rubber insulator samples with fly ash filler compositions ranging from 0% to 80% [13]. A previous study using coal fly ash as a filler in epoxy polymer material showed no significant improvement in its properties. The hydrophobicity of the epoxy polymer was inferior to that of silicone rubber, as evidenced by the comparison between the two materials [14].

In this study, we used the quadratic regression optimization method to help find the best composition for the mechanical performance of a SiR polymer insulator. Referring to the study "Optimization of PV Power Output Based on Tilt Angle at the PLN Institute of Technology Jakarta", the research aimed to assess the power output improvement with changing tilt angles using a quantitative correlation method and quadratic regression. The results showed an R^2 value of 0.9273 and a Root Mean Square Error (RMSE) of 0.160, indicating a very good model. The optimal tilt angle for maximizing the solar power output was found to be 33.7°, yielding a power output of 8.87 watt.

The studies mentioned above only focus on the effect of fly ash composition as a filler on the mechanical performance of SiR polymer insulators, but they do not address how to optimize the composition of fly ash to enhance the mechanical properties of the SiR polymer insulator. Therefore, this study aims to examine the impact of fly ash composition as a filler on the mechanical performance of SiR polymer insulators, while also optimizing these properties based on the fly ash composition in RTV 683 silicone rubber, using quadratic regression analysis.

METHODOLOGY

Quadratic Regression

The quadratic regression method of the optimization criteria in the experimental design is called a qualitative comparison of the comparison of various types of criteria to obtain various types of parameters. The optimization criterion is considered by p -means, with $-\infty \leq p \leq 1$ which the variation of p is between $-\infty$ dan 0. The quadratic regression model was described by Franz and Firedrich in 1987 [15]. The equation of the quadratic regression model is described below:

$$Y_{(\mathcal{X})} = \beta_0 + \beta_1 \mathcal{X}^1 + \beta_2\, \mathcal{X}^2 + \sigma e, \qquad \mathcal{X} \in [0,1] \qquad \text{..... (1)}$$

Where e is a random error with a mean value of 0 and a variance of 1 and $\sigma > 0$ is an unknown scale factor.

In the previous study entitled "Analysis of the Influence of Tilt Angle on Output Current in Photovoltaics Using the Regression Quadratic Method". This study uses the quadratic regression method which is used as a calculation of optimizing the angle of inclination of the output current at the PV. The research used Ms. software tools. Excel [16].

Then, research conducted by [17] The study "Optimization of Regenerator Operating Parameters and Thermal Insulation for Rotary Regenerative Thermal Oxidizer (r-RTO)" uses quadratic regression to optimize the thermal insulation thickness. The researcher found that this method helps improve both the regenerator's operating parameters and the insulation design.

Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error (MAPE) is an alternative method for evaluating model techniques used to measure the level of model accuracy of a model. RMSE is the average value of the number of absolute errors, a low MAPE value indicates that the variation in values produced by model approaches the variation in observations [18-20]. By using the equation (2) below:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \left|\frac{y_i - \hat{y}_i}{y_i}\right| \quad \ldots (2)$$

with

yi : actual request to i,
ŷi : forecasting result to i,
n : the amount of data.

RESULTS AND DISCUSSION

This article uses optimization modeling analysis by calculating quadratic polynomial regression of the order 2 by utilizing equation (1) where the X value is the number of fly ash composition variants as silicone rubber filler starting from 0% fly ash to 80% fly ash, then the Y value is the value obtained from several tests carried out on fly ash material against silicone rubber in units. In this research, the tensile strength test (kgf/mm^2) and elongation test (mm) were carried out.

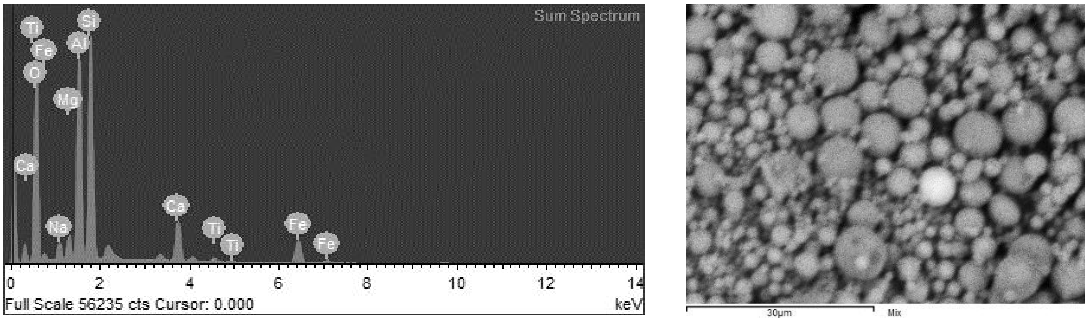
Characteristics of Fly Ash

This scientific article follows optimization analysis stages, building on previous research that used an experimental method with RTV 683 silicone rubber sourced from PT Matapel Chemical, a material readily available in the market. RTV 683 utilizes a hardening system based on a pure liquid acetoxylane catalyst, without mixing other elements. This silicone rubber was then combined with coal fly ash waste material for the study.

Fly ash is a coal waste material from PT Semen Tonasa Indonesia. Based on the ASTM C612 standard, the fly ash tested was type F fly ash with a high SiO2 mineral content. These contents can be seen through a Scanning Electron Microscope (SEM) [13].

The characteristics of coal fly ash depend on the quality of the combustion process, as shown in Figure 2.a shows that the majority of the fly ash content consists of SiO2, Fe2O3, and Al2O3 [21]. In this study it was reported that the characteristics of fly ash originate from chemical elements, fly ash size, microstructure and electrical resistance [22].

The Figure 2.b is shown the results of fly ash microstructure with using Scanning Electron Microscope (SEM) test by the microstructural fly ash structure. From the figure, the fly ash is in the form of a small particle that has an irregular size and shape[22].



(a) (b)

Figure 1. (a) Characteristics of fly ash Chemical Elements, (b) Coal fly ash (CFA) SEM test results

Characteristics of SiR

The chemical structure of SiR shown in Figure 2 Silicone Rubber (SiR) is an elastomer type material containing silicon atoms which is able to maintain stability at temperatures of -55 o C to +300 o C so as to provide characteristics such as weathering thermal stability, and anti-oxidation. Then, these characteristics can improve the electrical and mechanical properties [23].

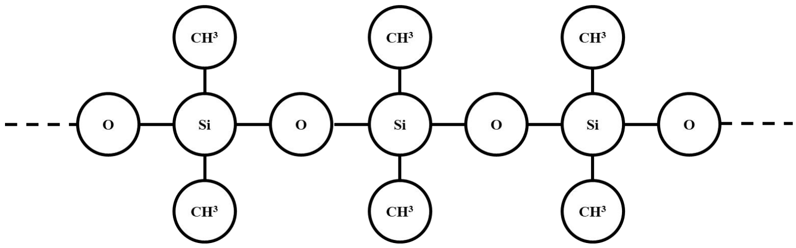


Figure 2. Chemical structure of SiR [28]

The testing of fly ash as a filler in RTV 683 silicone rubber insulators, based on ASTM D 412, was conducted by [24] The study "Testing Standards Assessment for Silicone Rubber" explains how to test silicone rubber using Biobrane® to check its properties. The tests followed the ASTM D 412 standard and were analyzed with statistical methods. The results showed less than 5% error, confirming the standard's accuracy. Another study tested fly ash as a filler in RTV 683 silicone rubber insulators, also using ASTM D 412, supporting its use for silicone rubber testing.

Optimization of Tensile Strength

Table 1 is summarized the result of various breakdown voltage values. Based on the results of taking fly ash tensile test data as RTV 683 silicone rubber filler, the result can be seen in Table 1. By using the data in Table 1, continue to look at the graph of the composition test value against the tensile strength test value, the test chart can be seen in Figure 3.

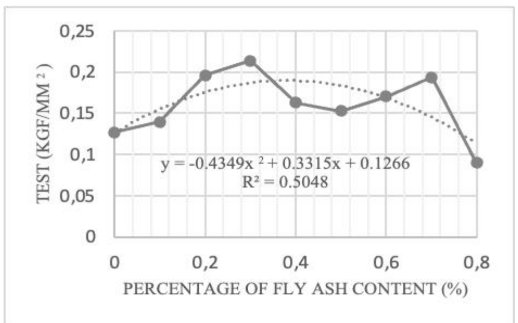


Figure 3. Quadratic regression graph of fly ash composition on tensile strength values

Table 1. Tensile strength test results

Sample code	Composition of fly ash against RTV	Composition (decimal)	Tensile Strength (kgf/mm^2)
SF0	Fly Ash 0%	0.0	0.1271
SF1	Fly Ash 10%	0.1	0.1394
SF2	Fly Ash 20%	0.2	0.1960
SF3	Fly Ash 30%	0.3	0.2136
SF4	Fly Ash 40%	0.4	0.1631
SF5	Fly Ash 50%	0.5	0.1530
SF6	Fly Ash 60%	0.6	0.1702
SF7	Fly Ash 70%	0.7	0.1934
SF8	Fly Ash 80%	0.8	0.0899

Note: Insulator testing using fly ash as filler.

Figure 3 shows the percentage of fly ash content (0% to 80%) forming a polynomial graph. The highest tensile strength values were observed at 30% and 70% fly ash composition. This indicates that adding fly ash as a filler influences the tensile strength of the material. Using MS Excel, the tensile strength (Y-axis) and fly ash composition (X-axis) were plotted, leading to the following polynomial quadratic regression equation model:

$$y = -0.4349x^2 + 0.3315x + 0.1266 \qquad \text{..... (3)}$$

The MAPE value is calculated from the polynomial quadratic regression model using the data in the Table 2.

Table 2. Calculation of accuracy of quadratic regression modeling tensile testing

X	Y	Ŷ	Y - Ŷ	(Y – Ŷ) ^{2}
0.0	0.1271	0.1266	0.00052000	0.00000027
0.1	0.1394	0.1554	-0.01601000	0.00025623
0.2	0.1960	0.1755	0.02045600	0.00041843
0.3	0.2136	0.1869	0.02672700	0.00071435
0.4	0.1631	0.1896	-0.02648000	0.00070144
0.5	0.1530	0.1836	-0.03059000	0.00093604
0.6	0.1702	0.1689	0.00126600	0.00000160
0.7	0.1934	0.1455	0.04788500	0.00229301
0.8	0.0899	0.1135	-0.02357000	0.00055531

Note: Quadratic regression modeling.

Table 2 shows the quadratic regression model. Using Equation 2, a MAPE value of 13.64% was found, indicating low error and confirming the model's accuracy. To find the best fly ash composition for RTV 683 silicone rubber insulators, Equation 3 is used, helping to calculate the optimal composition for the best performance:

$$\frac{dy}{dx} = 0$$

$$\Longleftrightarrow \frac{dy}{dx}(-0.4349x^2 + 0.3315x + 0.1266) = 0$$

$$\Longleftrightarrow 2(-0.4349 + 0,3315) = 0$$

$$\Longleftrightarrow x = \frac{0.3315}{0.8698}$$

$$\Longleftrightarrow x = 0.3811$$

From this process, a composition (x) of 0.3811 or in a composition percentage of 38.11% fly ash is obtained for RTV 683 silicone rubber and tensile strength optimum value is 0.19.

Optimization of Elongation Strength

Table 3 is shown various breakdown voltage values of silicone rubber filler for RTV 683.

Table 3. Elongation test results

Sample code	Composition of fly ash against RTV	Composition (decimal)	Elongation (mm)
SF0	Fly Ash 0%	0.0	345.00
SF1	Fly Ash 10%	0.1	158.85
SF2	Fly Ash 20%	0.2	140.40
SF3	Fly Ash 30%	0.3	114.73
SF4	Fly Ash 40%	0.4	94.16
SF5	Fly Ash 50%	0.5	93.62
SF6	Fly Ash 60%	0.6	73.80
SF7	Fly Ash 70%	0.7	61.90
SF8	Fly Ash 80%	0.8	39.17

Note: Insulator testing using fly ash as filler.

By using the data in Table 3, it is continued to look at the graph of the composition test value against the elongation test value, the test chart can be seen in Figure 4.

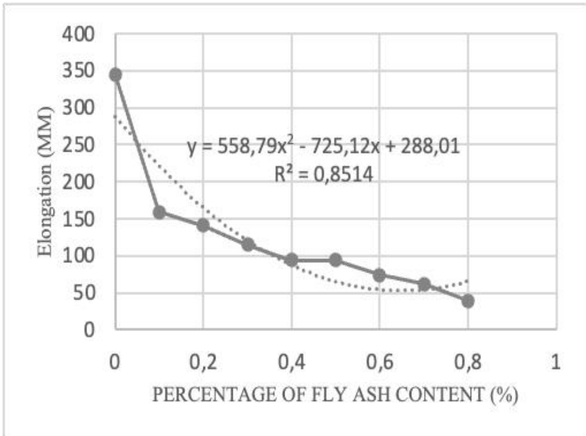


Figure 4. Quadratic regression graph of fly ash composition on elongation values

Figure 4 shows the percentage of fly ash content (0% to 80%) in a polynomial graph. Some fly ash compositions led to a significant decrease in elongation values. The graph clearly shows that adding fly ash as a filler affects the elongation strength of the material. Using MS Excel, the elongation value (Y-axis) and fly ash composition (X-axis) were plotted, resulting in the following polynomial quadratic regression equation model:

$$Y = 558.79x^2 - 725.12x + 288.01 \quad \ldots\ldots (4)$$

The MAPE value is calculated from the polynomial quadratic regression model using the data in the Table 4.

Table 4. Calculation of the accuracy of quadratic regression modeling Elongation Testing

X	Y	Ŷ	Y - Ŷ	(Y – Ŷ)^2
0.0	345.00	288.01	56.9900	3247.8600
0.1	158.85	221.09	-62.2359	3873.3070
0.2	140.40	165.34	-24.9376	621.8839
0.3	114.73	120.77	-6.0351	36.4224
0.4	94.16	87.37	6.7916	46.1258
0.5	93.62	65.15	28.4725	810.6833
0.6	73.80	54.10	19.6976	387.9954
0.7	61.90	54.23	7.6669	58.7814
0.8	39.17	65.54	-26.3696	695.3558

Note: Quadratic regression modeling.

Table 4 shows the quadratic regression model. Using Equation 4, a MAPE value of 24.75% was obtained, indicating a small error. To find the best fly ash composition for RTV 683 silicone rubber insulators, the optimization model balances stiffness and flexibility, using the median elongation value from the experiments:

$$Y = \frac{(345 + 39.17)}{2}$$

$$Y = 192.085$$

So that this median value together with equation (4) is used to obtain the optimal value of elongation and the following equation (5) is obtained:

$$558.79x^2 - 725.12x + 288{,}01 = 192.085 \qquad \text{. .... (5)}$$

From equation (5), then it is solved in order to obtain the best composition of fly ash to silicone rubber of 14.95% fly ash to RTV 683 silicone rubber and elongation optimum value is 192.094.

CONCLUSION

The research focused on the mechanical performance of Silicone Rubber (SiR) polymer insulators with fly ash as a filler, testing both tensile strength and elongation according to ASTM D 412 standards. Optimization of the fly ash composition in RTV 683 silicone rubber was then analyzed using quadratic polynomial regression (order 2). The results showed that the optimum fly ash composition for tensile strength was 38.11%, yielding a tensile strength of 0.189616 and a MAPE value of 13.64%. For elongation, the optimal fly ash composition was 14.95%, with an elongation value of 192.094 and a MAPE value of 24.75%.

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BIBLIOGRAPHY

[1] H. T. B. M. Petrus, M. Olvianas, W. Suprapta, F. A. Setiawan, A. Prasetya, and F. Anggara, "Cenospheres characterization from Indonesian coal-fired power plant fly ash and their potential utilization," *Journal of Environmental Chemical Engineering,* vol. 8, no. 5, p. 104116, 2020, doi: https://doi.org/10.1016/j.jece.2020.104116.

[2] A. Dindi, D. V. Quang, L. F. Vega, E. Nashef, and M. R. Abu-Zahra, "Applications of fly ash for CO2 capture, utilization, and storage," *Journal of CO2 Utilization,* vol. 29, pp. 82-102, 2019, doi: https://doi.org/10.1016/j.jcou.2018.11.011.

[3] K. Maqsood, "Multiobjective optimization of thermophysical properties of indonesian fly-ash nanofluid," *Materials Today: Proceedings,* vol. 49, pp. 1255-1262, 2022, doi: https://doi.org/10.1016/j.matpr.2021.06.304.

[4] Z. Adamczyk, J. Komorek, B. Białecka, J. Nowak, and A. Klupa, "Assessment of the potential of polish fly ashes as a source of rare earth elements," *Ore Geology Reviews,* vol. 124, p. 103638, 2020, doi: https://doi.org/10.1016/j.oregeorev.2020.103638.

[5] A. R. Gollakota, V. Volli, and C.-M. Shu, "Progressive utilisation prospects of coal fly ash: A review," *Science of the Total Environment,* vol. 672, pp. 951-989, 2019, doi: https://doi.org/10.1016/j.scitotenv.2019.03.337.

[6] B. Bielowicz, D. Botor, J. Misiak, and M. Wagner, "Critical elements in fly ash from the combustion of bituminous coal in major polish power plants," in *E3S Web of Conferences*, 2018, vol. 35: EDP Sciences, p. 02003, doi: https://doi.org/10.1051/e3sconf/20183502003.

[7] S. Dai *et al.*, "Composition and modes of occurrence of minerals and elements in coal combustion products derived from high-Ge coals," *International Journal of Coal Geology,* vol. 121, pp. 79-97, 2014, doi: https://doi.org/10.1016/j.coal.2013.11.004.

[8] A. Ravindran, M. Kamaraj, N. Vasanthmurali, V. Meghavarshini, and M. Balachandran, "Nanosilica reinforced EPDM silicone rubber blends: Experimental and theoretical evaluation of mechanical and solvent sorption properties," *Materials Today: Proceedings,* vol. 46, pp. 4381-4386, 2021, doi: https://doi.org/10.1016/j.matpr.2020.09.666.

[9] S. Patel, R. Sengupta, U. Puntambekar, and N. Shingne, "Effect of different types of silica particles on dielectric and mechanical properties of epoxy nanocomposites," *Materials Today: Proceedings,* vol. 44, pp. 1848-1852, 2021, doi: https://doi.org/10.1016/j.matpr.2020.12.014.

[10] B. Lv *et al.*, "Separation of unburned carbon from coal fly ash: Pre-classification in liquid–solid fluidized beds and subsequent flotation," *Process Safety and Environmental Protection,* vol. 165, pp. 408-419, 2022, doi: https://doi.org/10.1016/j.psep.2022.07.031.

[11] K. K. Kar, *Handbook of Fly Ash*. Butterworth-Heinemann, 2021.

[12] P. Chindaprasirt, P. Jitsangiam, and U. Rattanasak, "Hydrophobicity and efflorescence of lightweight fly ash geopolymer incorporated with calcium stearate," *Journal of Cleaner Production,* vol. 364, p. 132449, 2022, doi: https://doi.org/10.1016/j.jclepro.2022.132449.

[13] S. Manjang, R. P. Putera, Y. S. Akil, and I. Kitta, "Electrical and Mechanical Properties of Fly Ash Filled Silicone Rubber for High Voltage Insulator," *ARPN Journal of Engineering and Applied Sciences,* vol. 10, no. 17, pp. 7320-7327, 2015.

[14] I. Kitta, S. Manjang, W. Tjaronge, and R. Irmawaty, "Effect of coal fly ash filler in silicone rubber and epoxy resin as insulating material in wet environmental conditions," *International Journal of Mechanical and Mechatronics Engineering,* pp. 160402-3939, 2016.

[15] F. Preitschopf and F. Pukelsheim, "Optimal designs for quadratic regression," *Journal of statistical planning and inference,* vol. 16, pp. 213-218, 1987, doi: https://doi.org/10.1016/0378-3758(87)90070-X.
[16] S. Samsurizal, A. Makkulau, and C. Christiono, "Analisis Pengaruh Sudut Kemiringan Terhadap Arus Keluaran Pada Photovoltaic Dengan Menggunakan Regretion Quadratic Method," *Energi & Kelistrikan,* vol. 10, no. 2, pp. 137-144, 2018, doi: https://doi.org/10.33322/energi.v10i2.286.
[17] B. Sun, T. Zhao, L. Li, Z. Wang, P. Sun, and C. Peng, "Optimization of regenerator operating parameters and thermal insulation construction for rotary regenerative thermal oxidizer (r-RTO) based on thermal-fluid coupling method and quadratic regression model," *Case Studies in Thermal Engineering,* vol. 37, p. 102314, 2022, doi: https://doi.org/10.1016/j.csite.2022.102314.
[18] S. Makridakis *et al.*, "The accuracy of extrapolation (time series) methods: Results of a forecasting competition," *Journal of forecasting,* vol. 1, no. 2, pp. 111-153, 1982, doi: https://doi.org/10.1002/for.3980010202.
[19] F. Pakaja, A. Naba, and P. Purwanto, "Peramalan Penjualan Mobil Menggunakan Jaringan Syaraf Tiruan dan Certainty Factor," *Jurnal EECCIS (Electrics, Electronics, Communications, Controls, Informatics, Systems),* vol. 6, no. 1, pp. 23-28, 2012.
[20] U. Azmi, Z. N. Hadi, and S. Soraya, "ARDL METHOD: Forecasting Data Curah Hujan Harian NTB," *Jurnal Varian,* vol. 3, no. 2, pp. 73-82, 2020.
[21] A. Chandra, "Some investigations on fly ash resistivity generated in Indian power plants," in *Electrostatic Precipitation: 11th International Conference on Electrostatic Precipitation, Hangzhou, 2008*, 2009: Springer, pp. 399-405, doi: https://doi.org/10.1007/978-3-540-89251-9_81.
[22] T. Waris, Y. Murakami, N. Hozumi, T. Kawashima, S. Manjang, and I. Kitta, "Improved Performance of Silicon Rubber Insulation with Coal Fly Ash Micro Filler," *EPI International Journal of Engineering,* vol. 1, no. 2, pp. 81-86, 2018, doi: https://doi.org/10.25042/epi-ije.082018.13.
[23] M. Akbar, R. Ullah, and S. Alam, "Aging of silicone rubber-based composite insulators under multi-stressed conditions: an overview," *Materials Research Express,* vol. 6, no. 10, p. 102003, 2019.
[24] N. N. Azmi, M. N. A. Ab Patar, S. N. A. M. Noor, and J. Mahmud, "Testing standards assessment for silicone rubber," in *2014 International Symposium on Technology Management and Emerging Technologies*, 2014: IEEE, pp. 332-336.

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