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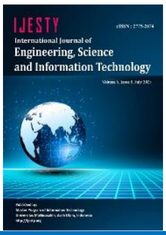

Performance of Soil Subgrade Improvement using Waste Material, Coconut Shell Charcoal

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Abstract

This study investigates using Coconut Shell Charcoal (ABK) as a stabilizing agent for clayey soils, aiming to enhance their suitability for road subgrade applications. The primary objective is to evaluate the effect of varying ABK concentrations (0%, 5%, 10%, and 15%) on the geotechnical properties of clay soil, particularly its compaction and load-bearing capacity. Laboratory tests, including compaction and California Bearing Ratio (CBR), were conducted to assess the influence of ABK on soil strength and stability. The results reveal that adding ABK significantly improves the soil's compaction characteristics and CBR values. The highest improvement was observed at 15% ABK, where the CBR value reached 22.22%, well above the minimum threshold required for road subgrade materials. Coconut shell charcoal has a good influence on increasing the CBR value of clay soil subgrade with each additional material. The R value of 0.963 obtained shows a very high correlation. Adding coconut shell charcoal to the subgrade soil positively affects the California Bearing Ratio value, increasing each variation. The study demonstrates that ABK, a sustainable agricultural waste product, provides an affordable and effective solution for enhancing the strength and stability of clay soils, making it a promising alternative to traditional stabilizers such as lime and cement. The findings have significant implications for road construction in regions with expansive and weak soils, offering a cost-effective and environmentally friendly method for soil stabilization. This research contributes to the growing body of knowledge on the use of agricultural waste in infrastructure development, emphasizing the potential of ABK in providing sustainable solutions for soil improvement in civil engineering applications.

Keywords: *Coconut Shell Charcoal, Soil Stabilization, Clay Soil, California Bearing Ratio,*

1. Introduction

The stability of road subgrades is a fundamental component in maintaining the durability and performance of transportation infrastructure, particularly in regions characterized by expansive and weak soils. [1][2][3]. Among the various challenges encountered in road construction, the low bearing capacity of clayey soils is particularly prevalent.[4] [5] [6]. These soils often display high plasticity and diminished strength, resulting in significant issues such as excessive settlement and deformation when subjected to load. [7][8][9]. Such problems not only jeopardize the structural integrity of roads but also necessitate frequent maintenance and costly repairs, highlighting the need for innovative solutions that enhance their structural properties. [10] [11]. In areas like Pekanbaru, Riau, where clayey soils are prominently found, stabilizing these soils is vital for establishing reliable and sustainable road infrastructure. [12]. As urbanization and infrastructure demands escalate, it becomes imperative to identify cost-effective strategies that can effectively improve the geotechnical properties of these problematic soils [13].

One promising methodology for ameliorating clay soil characteristics includes utilizing stabilizing agents derived from agricultural waste, such as coconut shell charcoal (ABK). Research indicates that coconut shell charcoal has a high silica content, which contributes to the enhancement of soil strength while simultaneously reducing plasticity [14] [15][16] [17]. Despite its promising attributes, the efficacy of ABK as a soil stabilizer in road subgrade applications remains under-researched, particularly concerning its impact on crucial parameters like soil compaction, California Bearing Ratio (CBR), and overall soil performance under load [16]. Bridging this knowledge gap is the primary motivation for the current study, which explores how varying percentages of ABK affect these essential soil properties.

Prior studies have investigated the impact of various materials on soil stabilization, such as lime, cement, and fly ash. For instance, research conducted by Agussalim assessed the influence of coconut shell charcoal on soil properties, revealing that a mixture containing up to 10% charcoal significantly enhanced soil strength. [18][19]. Similarly, research evaluating how ABK affected soil compaction discovered improved dry density with added mixtures. [11][17]. These findings indicate the potential for ABK to be utilized effectively in various soil improvement applications. Nonetheless, a comprehensive assessment delineating the connection between ABK content, CBR values, and overall performance in road subgrade contexts remains scarce.

This research uniquely differentiates itself from prior investigations by encompassing a broader exploration of how diverse percentages of ABK—specifically 0%, 5%, 10%, and 15%—influence the soil characteristics of clay soils designated for subgrade stabilization in road construction. Though earlier studies have established ABK's advantageous effects on soil compaction and strength, few have conducted extensive analyses considering a range of ABK concentrations and their direct impacts on CBR, which is vital for ascertaining the bearing capacity of subgrade soils [20]. By undertaking a series of methodical laboratory tests using local clay soils from Pekanbaru, the present study seeks to enhance understanding concerning the optimal quantity of ABK necessary for effective soil stabilization in road construction applications. Excessive settlement will cause structural damage to the building frame [21].

The underlying hypothesis of this inquiry is predicated on the assumption that incorporating coconut shell charcoal will substantially upgrade both the strength and compaction attributes of clay soils, thereby augmenting CBR values and the overall suitability of these soils for usage as subgrade materials. The anticipated findings of this research endeavor hold the potential to yield practical recommendations aimed at enhancing the performance of clayey soils, offering a sustainable and economically viable solution tailored for road construction, especially in regions replete with coconut shell waste.

While significant strides have been made in understanding various soil stabilization techniques, considerable gaps remain, particularly regarding the application of agricultural waste products like coconut shell charcoal in regions with clayey subgrades. As methodologies evolve, integrating sustainable solutions into infrastructure development practices becomes increasingly essential, aligning economic and environmental considerations to forge a resilient groundwork for future road networks across challenging terrains.

2. Method

This research investigates the enhancement of clay soil using coconut shell charcoal (ABK) for road subgrade stabilization. The analysis unit in this study is the clayey soil taken from the Tenayan Raya District of Pekanbaru, Riau, which is commonly used as subgrade material in road construction. The methodology applied is experimental, focusing on the laboratory-based testing of soil properties after the addition of different concentrations of ABK.

2.1. Research Approach

The research follows a quantitative experimental approach, where controlled laboratory tests are used to assess the impact of varying percentages of ABK on the geotechnical properties of the clay soil. The experiment is designed to evaluate the physical and mechanical characteristics of the soil, specifically its California Bearing Ratio (CBR), compaction, and consistency limits. Four different concentrations of ABK are tested: 0%, 5%, 10%, and 15%. The primary data collected include measurements of soil strength, density, and moisture content, while secondary data are obtained from literature on previous studies of soil stabilization techniques.

2.2. Data Sources

The primary data are derived from the laboratory tests performed on the soil samples and ABK mixtures. The tests conducted include:

1. Sieve Analysis: To determine the particle size distribution of the soil.
2. Specific Gravity Test: To measure the density of the soil particles.
3. Atterberg Limits Test: To evaluate the plasticity characteristics of the soil.
4. Compaction Test (Standard Proctor Test): To determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil.
5. California Bearing Ratio (CBR) Test: To assess the soil's load-bearing capacity with and without ABK addition, under both soaked and unsoaked conditions.

The secondary data are gathered from previous studies, scientific journals, and books on soil stabilization and using coconut shell charcoal (ABK) as a stabilizing agent. These sources provide context and comparison for the results obtained in the laboratory tests.

2.3. Data Collection

The data collection process involves the following steps:

1. Soil Sampling: Clayey soil is collected from the Tenayan Raya District, Pekanbaru, which is known for its expansive clay soils. The soil is collected from the topsoil layer to ensure consistency with typical road subgrade materials.
2. Preparation of ABK Mixtures: Coconut shell charcoal is processed and mixed with the clay soil at different ratios: 0%, 5%, 10%, and 15%. The mixtures are thoroughly homogenized to ensure uniform distribution of the ABK.
3. Laboratory Testing: The prepared soil-ABK mixtures are subjected to various laboratory tests, including compaction, sieve analysis, Atterberg limits, and CBR testing, to evaluate the changes in soil properties at each ABK concentration.

2.4. Data Analysis

The collected data are analyzed using statistical methods to determine the correlation between the ABK concentration and the soil properties. The analysis includes:

1. Descriptive Statistics: To summarize the results of each test (e.g., mean, standard deviation) and compare the properties of soil at different ABK concentrations.
2. Correlation Analysis: To determine the relationship between the addition of ABK and the soil's CBR, compaction, and plasticity.

3. Graphical Analysis: The data are presented in graphical formats to visualize soil performance trends with varying ABK percentages.

3. Results and Discussion

The results of this study were derived from a series of laboratory tests aimed at evaluating the effect of coconut shell charcoal (ABK) on the geotechnical properties of clay soil, particularly focusing on compaction, California Bearing Ratio (CBR), and consistency limits. The results are detailed below, supported by relevant tables and graphical representations.

3.1. Soil Physical Properties

Before the addition of ABK, the physical properties of the clay soil were analyzed, and the specific gravity of the soil was found to be 2.527 g/cm³, which is typical for clayey soils. The Atterberg limits were measured, revealing a liquid limit (LL) of 24%, a plastic limit (PL) of 14.89%, and a plasticity index (PI) of 9.11%. These results indicate that the soil is a low-plasticity clay, generally favorable for stabilization using additives like ABK.

3.2. Compaction Characteristics

The compaction test results demonstrated the effects of ABK on the soil's maximum dry density (MDD) and optimum moisture content (OMC). The following table presents the compaction results for each ABK concentration:

Table 1: compaction results for each ABK concentration

ABK Percentage	Maximum Dry Density (MDD) (g/cm³)	Optimum Moisture Content (OMC) (%)
0% ABK	1.60	9.6
5% ABK	1.45	17
10% ABK	1.44	22
15% ABK	1.40	19

The results of Table 1 indicate that with the addition of ABK, the maximum dry density decreases while the optimum moisture content increases. This trend is typical for soil stabilization using organic materials, as the addition of ABK increases the porosity of the soil, requiring more moisture for optimal compaction.

3.3. California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test measures the load-bearing capacity of soil, which is crucial for assessing its suitability as a subgrade material in road construction. The CBR values for each ABK concentration at different penetrations (10, 30, and 65 blows) are shown in the table below:

Table 2: California Bearing Ratio (CBR) test

ABK Percentage	CBR (100% MDD)	CBR (95% MDD)	CBR (10 Blows)	CBR (30 Blows)	CBR (65 Blows)
0% ABK	2.10%	1.71%	1.40%	2.00%	2.73%
5% ABK	5.23%	4.20%	3.42%	6.89%	8.22%
10% ABK	18.00%	9.80%	3.42%	7.78%	20.00%
15% ABK	21.00%	13.00%	5.33%	13.33%	22.22%

The results of Table 2 indicate that ABK significantly enhances the CBR of the clay soil. The CBR value at 100% Maximum Dry Density (MDD) increases from 2.10% for the soil without ABK to 21.00% for the soil with 15% ABK, well above the minimum requirement of 6% for subgrade materials in road construction. The CBR values at 65 pukulan show a similar trend, with the maximum improvement observed at 15% ABK, reaching 22.22%.

3.4. Graphical Representation of CBR vs. ABK Content

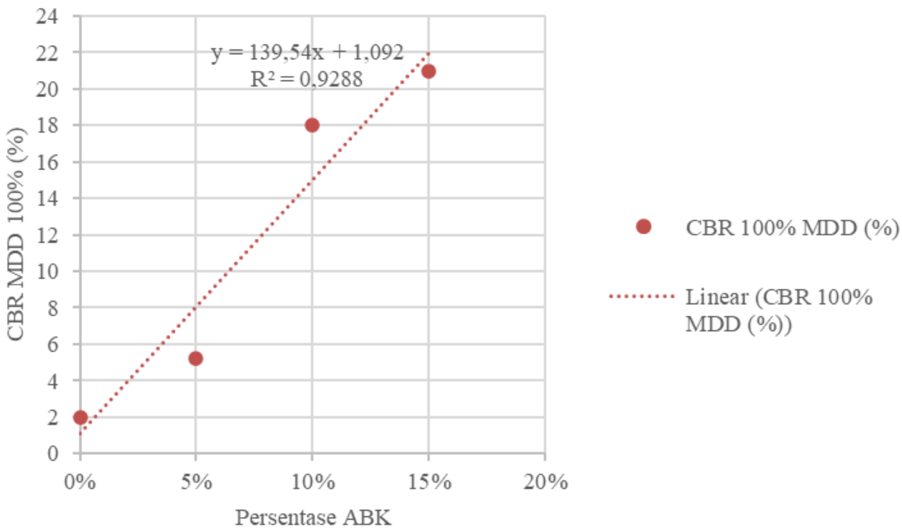

Fig 1. Graphical Representation of CBR vs. ABK Content

Graph one shows an upward trend in CBR with increasing ABK content, particularly in the 65-blows test, which is the most significant for determining the soil's bearing capacity for subgrade applications. The CBR value of the soil without the addition of ABK is 2.1%, at 5% ABK, the CBR reaches a value of 5.23% and at 10% ABK, the CBR reaches a value of 18% and at 18% ABK, the CBR reaches the highest value of 22.22%

Adding coconut shell charcoal (ABK) significantly improved the soil's compaction and bearing capacity. The most notable improvement was observed at 15% ABK, where the soil's CBR reached 21%, well above the minimum requirement for road subgrade materials. These results confirm that ABK can be used effectively to enhance the geotechnical properties of clay soil, making it a viable and sustainable option for road subgrade stabilization.

The equation graph above obtained an R^2 value of 0.9288, so that an R correlation value of 0.964 was obtained, which, when viewed on the graph, shows a sound effect of coconut shell charcoal in line with the increase in the CBR value of the clay subgrade at each additional material. The R value of 0.964 obtained shows a very high correlation.

This study aimed to address one of the most pressing challenges in road construction: stabilizing clayey soils with low bearing capacity. The results presented here highlight the significant improvements in clay soil's compaction and load-bearing capacity (CBR) by incorporating coconut shell charcoal (ABK). These findings have substantial implications for improving soil quality for road subgrade applications, particularly in regions like Pekanbaru, Riau, where clayey soils predominate. The results confirm the hypothesis that ABK can enhance the geotechnical properties of clay soils and provide new insights into the optimal concentration of ABK required to achieve the best soil stabilization.

The primary research problem addressed by this study is the low bearing capacity of clayey soils, which poses significant challenges in road construction. When subjected to load, these soils typically exhibit high plasticity, low strength, and excessive settlement. These characteristics often result in deformation and frequent maintenance requirements, particularly in expansive soils like those found in Pekanbaru, Riau. [10], [12], [20]. Effective soil stabilization methods that improve the strength and compaction of these soils are critical for ensuring the durability and performance of transportation infrastructure.

This study's findings confirm that adding ABK, a byproduct of coconut shells, significantly enhances clayey soils' compaction and CBR values. The results demonstrate that 15% ABK is the optimal concentration for improving soil strength, with the CBR value reaching 22.22% in the 65-pukulan test, far exceeding the minimum requirement of 6% for subgrade materials. The use of ABK addresses the core issue of low-bearing capacity by enhancing the soil's ability to bear loads, making it more suitable for use in road subgrades. [11], [13].

The research is directly relevant to the pressing need for sustainable, cost-effective, and environmentally friendly solutions to soil stabilization, especially in areas with abundant coconut waste. By utilizing ABK, this study offers a viable alternative to conventional stabilizers, which are often expensive and environmentally harmful.

This study builds on previous research exploring various stabilizing agents for clay soils, such as lime, cement, and fly ash. [18]. Previous studies have also demonstrated that ABK has the potential to improve soil strength and compaction. [11], [19]. For instance, Agussalim et al. [18] ABK enhanced soil strength significantly when mixed with 10% ABK; similarly, Won et al. [11] observed improved soil dry density with ABK addition, supporting the idea that ABK is an effective stabilizing agent.

However, unlike these studies, which mainly focused on soil compaction or strength improvements, this study is more comprehensive in its assessment. It explores a broader range of ABK concentrations (0%, 5%, 10%, and 15%). It evaluates its impact on the California Bearing Ratio (CBR), a critical parameter for determining the load-bearing capacity of subgrade materials. This is especially important because CBR is a more direct measure of a soil's suitability for road construction than other indicators such as dry density. The study's focus on CBR helps to fill the knowledge gap regarding the specific effect of ABK on soil performance under load, which has been underexplored in previous literature [16].

Additionally, while earlier studies have explored the effects of ABK on soil properties in isolation, this study offers a more holistic perspective by systematically analyzing the relationship between ABK content and CBR values at different penetration levels (10, 30, and 65 pukulan). This comprehensive approach provides valuable insights into the optimal ABK content for road subgrade stabilization, a factor that has not been fully explored in previous research.

The findings of this study hold significant implications for road construction and soil stabilization practices, particularly in regions with expansive and problematic soils. The improvement in CBR values with ABK addition indicates a substantial increase in the soil's ability to bear loads, which is crucial for the performance and longevity of road infrastructure. The results show that 15% ABK is the most effective concentration for enhancing the CBR, reaching a maximum value of 22.22% at 65 pukulan. This improvement exceeds the minimum required CBR of 6% for road subgrade materials, confirming that ABK is a viable solution for soil stabilization.

These findings also align with the growing demand for sustainable and cost-effective solutions in infrastructure development. As urbanization continues to escalate, particularly in regions like Pekanbaru, where coconut waste is abundant, ABK offers an environmentally friendly alternative to traditional soil stabilizers like lime and cement. The use of ABK not only improves the soil's properties but also contributes to the circular economy by utilizing agricultural waste materials that would otherwise be discarded.

Moreover, this study's results underscore the economic feasibility of using ABK as a stabilizing agent, particularly in developing regions where costs and sustainability are significant concerns. Incorporating ABK can reduce the costs associated with purchasing traditional stabilizers and the environmental footprint of soil stabilization, making it an ideal solution for cost-conscious and environmentally aware construction projects. [12].

While conventional stabilizing agents such as lime, cement, and fly ash have been widely used in soil stabilization, they have several drawbacks, including high costs, energy consumption, and carbon emissions. [18]. In contrast, ABK is an agricultural byproduct, making it an affordable, sustainable, and low-carbon alternative. Unlike lime or cement, which require significant energy inputs for production, ABK offers a low-carbon stabilization method, aligning with global sustainability trends. [19].

Using ABK as a stabilizing agent offers additional environmental benefits, particularly by reducing waste generated from coconut processing. This aligns with the waste minimization principles and resource efficiency central to sustainable development practices. Furthermore, unlike some chemical stabilizers, ABK does not produce harmful emissions or waste products.

This study demonstrates that incorporating coconut shell charcoal (ABK) into clay soils significantly improves their compaction and load-bearing capacity (CBR), making them more suitable for road subgrade applications. The optimal ABK concentration for achieving the best soil stabilization is 15%, which resulted in the highest CBR values and is well above the minimum required threshold for road construction materials.

The results of this study contribute to the growing body of knowledge on the use of sustainable and cost-effective stabilizers like ABK in soil improvement. This research addresses the practical challenges associated with the low bearing capacity of clay soils and offers an environmentally friendly alternative to conventional soil stabilizers. The findings highlight the importance of integrating sustainable solutions in infrastructure development, particularly in regions with abundant agricultural waste like Pekanbaru.

Future research could explore the long-term durability of ABK-treated soils under real-world conditions and the synergistic effects of combining ABK with other sustainable materials, such as lime or fly ash, to enhance soil performance further. Additionally, investigating the economic feasibility of large-scale ABK application in road construction would be valuable in evaluating its potential for widespread adoption.

4. Conclusion

This study presents a significant advancement in soil stabilization by exploring the effectiveness of coconut shell charcoal (ABK) as a stabilizing agent for clay soils, particularly in road subgrade applications. The novelty of this research lies in its comprehensive examination of how varying percentages of ABK (0%, 5%, 10%, and 15%) impact critical soil properties such as compaction, California Bearing Ratio (CBR), and overall soil performance under load.

The findings demonstrate that adding ABK notably enhances clay soils' compaction characteristics and bearing capacity, with the most pronounced improvement observed at 15% ABK. The CBR value has increased, far exceeding the minimum % requirement for road base material, which is 6%. This makes ABK an effective solution for improving the strength and stability of clay soils, providing a cost-effective and sustainable alternative to traditional stabilizers like lime and cement.

What sets this research apart from previous studies is the holistic approach of analyzing ABK concentrations across multiple soil parameters, including the comprehensive evaluation of CBR, which has been insufficiently explored in past studies. By addressing a critical gap in the literature, this study offers a deeper understanding of the optimal concentration of ABK necessary for soil stabilization in road construction.

Moreover, the results emphasize the environmental benefits of using ABK, a waste product from the coconut industry, for soil improvement. This approach offers a sustainable and cost-effective solution and contributes to reducing agricultural waste, aligning with the principles of a circular economy.

The outcomes of this research provide practical implications for road construction in regions with clayey soils, offering a scalable, environmentally friendly, and economically viable solution to soil stabilization. Using ABK can potentially revolutionize how problematic soils are treated, especially in developing regions with limited access to expensive stabilizing agents.

Future studies could focus on the long-term performance of ABK-stabilized soils under real-world traffic loads and environmental conditions. Additionally, research exploring the combination of ABK with other sustainable stabilizers could further improve soil properties, paving the way for more innovative and green solutions in civil engineering and infrastructure development.

This study provides compelling evidence that ABK can effectively enhance the geotechnical properties of clay soils, offering a promising pathway toward more sustainable and cost-effective soil stabilization methods for road construction.

References

[1] S. Kumar and S. K. Singh, "Subgrade soil stabilization using geosynthetics: A critical review," *Mater. Today Proc.*, 2023, doi: 10.1016/j.matpr.2023.04.266.

[2] M. Sadillah, A. K. Arifianto, and D. A. M. Amaral, "Pengaruh Kondisi Tanah Terhadap Kerusakan Dengan Menggunakan Metode Road Condition Index (RCI) Pada Ruas Jalan Pronoyudo Kecamatan Junrejo-Kota Batu," *Cantilever J. Penelit. Dan Kaji. Bid. Tek. Sipil*, 2022, doi: 10.35139/cantilever.v10i2.116.

[3] D. Zhang, "Discussion on Construction Technology of Road Subgrade in Civil Engineering," *Insight - Civ. Eng.*, 2020, doi: 10.18282/ice.v3i2.355.

[4] A. B. Espinosa, V. Revilla-Cuesta, M. Skaf, R. Serrano-López, and V. Ortega-López, "Strength performance of low-bearing-capacity clayey soils stabilized with ladle furnace slag," *Environ. Sci. Pollut. Res.*, 2023, doi: 10.1007/s11356-023-29375-y.

[5] N. A. Saparudin, N. Kasim, K. A. Taib, W. N. A. W. Azahar, N. A. Kasim, and M. Ali, "IMPROVEMENT OF PROBLEMATIC SOIL USING CRUMB RUBBER TYRE," *IIUM Eng. J.*, 2022, doi: 10.31436/IIUMEJ.V23I2.2293.

[6] E. H. Quispe, C. G. R. Salvador, J. J. M. Aranda, N. I. V. Montoya, and I. Y. P. Morejón, "Improvement of Bearing Capacity with Cement, Lime and Brick Waste in Soft Soils for Foundation Purposes," *Civ. Eng. Archit.*, 2024, doi: 10.13189/cea. 2024.120108.

[7] G. Wang, X. Zhang, X. Liu, H. Gao, R. An, and L. Yan, "Engineering geological characterization of micaceous residual soils considering effects of mica content and particle breakage," *Eng. Geol.*, 2023, doi: 10.1016/j.enggeo.2023.107367.

[8] A. Barzgar Torghabeh, M. Tehranizadeh, and A. Taslimi, "Probability of collapse evaluation for high-rise reinforced concrete buildings in the event of near-fault earthquakes and soil-structure interaction effects," *Structures*, 2023, doi: 10.1016/j.istruc.2023.06.113.

[9] R. Ratna Prasad, T. Venkateswararao, and D. Auditya Sai Ram, "Use of lime and waste plastic fibers for subgrade stabilization," *Int. J. Eng. Adv. Technol.*, 2018.

[10] A. Saand, M. A. Zardari, M. A. Keerio, S. Shaikh, and D. K. Bangwar, "Suitability of Brick Kiln Waste as a Stabilizer to Clayey Soils," *Sci. Iran*, vol. 0, no. 0, p. 0, 2018, doi: 10.24200/sci. 2018.50198.1569.

[11] M.-S. Won, C. P. Langcuyan, and Y. Gao, "A Study on the Utilization of Clayey Soil as Embankment Material Through Model Bearing Capacity Tests," *Appl. Sci.*, vol. 10, no. 7, p. 2315, 2020, doi: 10.3390/app10072315.

[12] H. Mardesci, S. Santosa, N. Nazir, and R. A. Hadiguna, "Analysis of Value-Added and Calculation of Production Cost in the Production of Processed Coconut Product," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 11, no. 2, pp. 776–782, 2021, doi: 10.18517/ijaseit.11.2.11593.

[13] M. Ammaiappan and K. Natarajan, "Geotechnical Performance of Stabilized Weak Soils Using a Combination of Waste Tyre Powder and Kota Stone Powder," *Eatp*, 2024, doi: 10.53555/kuey.v30i5.2956.

[14] B. Wasis, S. B. Ghaida, and B. Winata, "Application of Coconut Shell Charcoal and NPK Fertilizer Toward Acacia Mangium Growth on the Soil of Ex-Limestone Mining in Bogor, Indonesia," *Arch. Agric. Environ. Sci.*, vol. 4, no. 1, pp. 75–82, 2019, doi: 10.26832/24566632.2019.0401012.

[15] U. Umaisaroh, M. Alaydrus, E. Handoko, and N. Alferinanda, "Design of Biomaterial Absorber Using Coconut Shell Charcoal for 38 GHz Frequency," *J. Phys. Conf. Ser..*, vol. 2866, no. 1, p. 12027, 2024, doi: 10.1088/1742-6596/2866/1/012027.

[16] H. Porawati, S. Y. B. Zaqy, S. Sepriyanto, B. S, and F. Sibarani, "Design and Development of Coconut Shell Charcoal Machine Using Pyrolysis Method," 2024, doi: 10.4108/eai. 21-9-2023.2342966.

[17] A. D. P. Putera, I. W. Warmada, D. H. Amijaya, W. Astuti, I. G. Sukadana, and H. T. B. M. Petrus, "A Comparison Study of Nickel Laterite Reduction Using Coal and Coconut Shell Charcoal: A FactSage Simulation," *Int. J. Technol.*, vol. 14, no. 2, p. 267, 2023, doi: 10.14716/ijtech.v14i2.5808.

[18] A. Agussalim, A. Khairana, M. Rajab, M. Rezky, and U. Dwiyanti, "Mutu Dan Karakteristik Penyalaan Briket Arang Tempurung Kelapa Dengan Aplikasi Lapisan Arang Sengon Pada Permukaannya," *J. Rekayasa Proses*, vol. 16, no. 1, p. 49, 2022, doi: 10.22146/jrekpros. 70277.

[19] A. Bhardwaj and R. K. Sharma, "Bearing Capacity Evaluation of Shallow Foundations on Stabilized Layered Soil Using ABAQUS," *Stud. Geotech. Mech.*, vol. 45, no. 1, pp. 55–71, 2022, doi: 10.2478/sgem-2022-0026.

[20] H. Mardesci, S. Santosa, N. Nazir, and R. A. Hadiguna, "Identification of Prospective Product for the Development of Integrated Coconut Agroindustry in Indonesia," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 9, no. 2, pp. 511–517, 2019, doi: 10.18517/ijaseit.9.2.7172. [21] S. Srihandayani, L. D. Putri, N. Kurniasih, "Bearing Capacity of Floating Foundations Used PVC (Poly Vinyl Chloride) on Soft Soil with The Scale Model in The Field, Int. J. Eng. Techno., vol 7 (2.5), pp 84-87, 2018, doi: 10.14419/ijet.v7i2.5.13957.