International Journal of GEOMATE, July, 2025 Vol.29, Issue 131, pp. 48-55
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2025.131.4842
Geotechnique, Construction Materials and Environment

SUSTAINABLE SOFT CLAY STABILIZATION USING RICE HUSK ASH AND WASTE SPENT CATALYST FROM RESIDUAL CATALYTIC CRACKING

*Syahril S[1], Sandy D Sagala[2], Dian Adiputra Purba[3], Kevin Hutama Syahputra[4]

[1,2,3,4] Department of Civil Engineering, Faculty of Engineering, Polytechnic of Bandung State, Indonesia

*Corresponding Author, Received: 02 Dec. 2024, Revised: 17 March 2025, Accepted: 20 March 2025

ABSTRACT: The chemical stabilization of soft clay aims to improve its bearing capacity, enabling it to support structural loads effectively. This study investigates the effectiveness of Rice Husk Ash (RHA) and Spent Catalyst RCC 15 (RCC) as stabilizing agents. The research begins with soil sampling and index property analysis, followed by engineering tests to evaluate the Unconfined Compressive Strength (UCS), Atterberg limits, and compaction characteristics. The stabilization mixtures were composed of 6% RHA, with RCC 15 varying at 5%, 7%, 9%, and 11%. The Plasticity Index (PI) decreased from 29.45% to 25.55% with increasing RCC 15 content, indicating reduced plasticity and improved stability due to pozzolanic cementation. The compaction test results show that the Maximum Dry Density (MDD) increased to 1.355 g/cm³, while the Optimum Moisture Content (OMC) decreased to 25.67%, demonstrating improved densification. UCS testing revealed a significant strength increase, with the highest compressive strength of 0.217 MPa (2.17 kg/cm²) achieved at 6% RHA and 11% RCC 15, marking a 4.4-fold improvement over untreated soil. These findings confirm that RHA and RCC 15 significantly enhance the strength, density, and plasticity characteristics of soft clay, making them viable alternatives for soil stabilization. The study highlights the sustainability benefits of using industrial byproducts in geotechnical applications, reducing dependence on conventional materials while enhancing soil performance.

Keywords: Soft Clay, Stabilization, Rice Husk Ash, Spent Catalyst RCC 15, Compressive Strength

1. INTRODUCTION

Soil is a fundamental component in construction, especially in foundation engineering [1], as it must have sufficient strength to support the loads of superstructures built upon it[2]. However, soils at many construction sites often exhibit limitations, including low permeability, high plasticity index, and poor compressibility [3]. These unfavorable properties can compromise infrastructure stability and potentially lead to structural failures. Thus, improving soil engineering characteristics through stabilization is critical[4].

Soil stabilization is a widely used civil engineering technique designed to modify and enhance the mechanical and physical properties of soft soil to make it more sustainable for construction purposes[5]. This process generally involves the addition of specific materials to increase soil bearing capacity, reduce plasticity, and improve compaction characteristics[6]. Stabilization is especially important in soils with low strength, high plasticity, excessive swelling potential, or inadequate gradation[7].

A sustainable and efficient material for soil stabilization is Rice Husk Ash (RHA), waste product derived from rice milling[8]. Rice Husk Ash (RHA) is rich in silica (SiO_2) and possesses pozzolanic properties, enabling it to react with calcium hydroxide in the presence of moisture to form calcium silicate hydrates (C-S-H), which contribute to increased soil strength. Numerous studies have shown that incorporating RHA can significantly enhance the compressive strength and reduce the swelling potential of clayey soils, making it an ideal stabilizing agent[9].

Another innovative material gaining attention in soil stabilization is the Spent RCC 15 Catalyst, a byproduct of petroleum refining industries such as PT. Pertamina[10]. RCC 15 is rich in silica, ferrous compounds, and alumina, which also possess pozzolanic properties. The combined use of RHA and RCC 15 in stabilizing soft clay soils offers an environmentally friendly approach, as both materials are industrial byproducts[10]. This strategy not only minimizes waste but also enhances the load-bearing capacity of soil, reduces settlement, and improves its overall engineering properties.

Recent international studies support the application of these pozzolanic materials in soil stabilization[11]. Research has indicated that adding rice husk ash (RHA) can enchance the unconfined compressive strength (UCS) of soft soil by up to 50%[5]. Furthermore, incorporating catalysts such as RCC 15 improves durability and resistance to environmental factors, including moisture fluctuations. Additionally, the use of these materials helps mitigate the environmental impact associated with conventional soil stabilization methods, such as cement or lime, which are energy-intensive and contribute to carbon emissions[12].

In conclusion, the combined application of Rice Husk Ash and Spent RCC 15 Catalyst offers a promising and sustainable approach to improving the geotechnical properties of weak soils. This method not only enhances soil structural performance but also promotes industrial waste recycling, aligning with global efforts toward more sustainable construction practices[13].

Soil stabilization is crucial in construction, particularly when dealing with weak soils characterized by high plasticity, poor permeability, and low strength. Traditional stabilizers such as cement and lime have been widely used but are costly and contribute to carbon emissions. This study introduces an alternative approach using RHA and RCC 15, which are rich in silica and alumina, enabling pozzolanic reactions that improve soil properties. Compared to lime and cement, RHA and RCC 15 offer a cost-effective and sustainable solution, reducing reliance on conventional materials while addressing industrial waste disposal issues.

2. RESEARCH SIGNIFICANCE

This research highlights a sustainable and cost-effective approach to soil stabilization in geotechnical engineering. By incorporating Rice Husk Ash (RHA) and Spent RCC 15 Catalyst—both industrial byproducts—the study provides an eco-friendly alternative to traditional stabilizers like cement, reducing carbon emissions and promoting waste recycling. The use of these pozzolanic materials enhances the load-bearing capacity, compressive strength, and overall stability of soft clay soils. Additionally, this approach lowers material costs and addresses waste disposal challenges. By examining the combined effects of RHA and RCC 15, this study bridges a research gap and contributes to more resilient and sustainable construction practices.

3. MATERIAL AND METHODS

3.1 Rice Husk Ash (RHA) Waste

Rice husk, a byproduct of the rice milling process, accounts for approximately 20% of the total weight of rice and yields ash with a silica content exceeding 90% when burned[14]. This silica-rich Rice Husk Ash (RHA) exhibits pozzolanic properties, allowing it to react with calcium hydroxide to form beneficial compounds such as calcium silicate hydrate (C-S-H)[15]. Visually gray in color, RHA functions as a filler in construction applications, effectively occupying voids between coarse aggregates to enhance density and reduce permeability, which ultimately improves the durability of mixtures[16].

Agricultural waste, such as rice husk ash (RHA), is commonly utilized in chemical soil stabilization techniques due to its abundance[17]. In addition, the Philippines' top rice-producing provinces produce about 9 million tons of rice annually. This large-scale production is accompanied by a significant amount of rice husk ash waste, which poses both an environmental challenge and an opportunity for potential reuse in various applications[9]. The potential of RHA in the field of soil stabilization is significant.

Fig. 1 Rice husk ash

Table 1 Chemical Elements Of Rice Husk Ash[18]

Oxide Composition (%)	RHA
SiO_2	94.47
Al_2O_3	0.92
Fe_2O_3	1.08
CaO	0.87
MgO	3.18
TiO_2	0.04

This table shows that RHA has a primary composition of silicon dioxide (SiO_2) at 93.47%, making it a highly pozzolanic material that contributes to soil stabilization reactions and the production of geopolymer-based concrete . Research has demonstrated RHA's effectiveness in soil stabilization and concrete production, highlighting its ability to ameliorate compressive strength, decrease plasticity, and improve the load-bearing capacity of weak soils[19]. Its fine particle size and high specific surface area enable RHA to act as a binder, facilitating better compaction and structural integrity[20,21]. Moreover, the utilization of RHA aligns with sustainable construction practices by decreasing dependence on traditional cement, thus reducing carbon emissions[22]. In summary, RHA is a valuable material that enhances the physical and mechanical properties of construction materials, supporting more environmentally friendly engineering solutions[23,24].

3.2 Spent Catalyst RCC 15 Waste

Spent Catalyst RCC (Residium Catalytic Cracking) 15 is a byproduct produced during the kerosene distillation process at PT. Pertamina RU VI in Balongan, West Java. This waste material possesses pozzolanic properties, making it a valuable resource for construction applications[25]. It comprises various components, including alumina, silica oxide, iron, and other elements that enhance its reactivity when mixed with water and calcium hydroxide[10].

One of the key advantages of Spent Catalyst RCC 15 is its significant availability, with production levels reaching approximately 20 tons per day. This substantial output presents a unique opportunity for its use in construction projects, as it can be sourced at no cost. By utilizing this waste material, the construction industry can address environmental concerns related to waste disposal while simultaneously improving the performance of construction materials [26].

Fig. 2 Spent catalyst rcc 15

Table 2 Chemical Elements Of Spent Catalyst RCC 15 [10]

Type	Characteristic (%)
$Si0_2$	47.13
Al_2o_3	45.34
Fe_2O_3	0.61
CaO	0.16
Na_2O	0.45
MgO	0.26

The chemical composition of Spent Catalyst RCC 15, as detailed in the accompanying table, underscores its potential benefits for soil stabilization and various engineering applications. The pozzolanic materials present in RCC 15 can enhance the strength and durability of soil and concrete mixtures, contributing to more sustainable and efficient construction practices. In summary, Spent Catalyst RCC 15 represents a promising solution for improving construction materials while promoting waste recycling within the industry.

3.3 Selection of Stabilizers

The choice of 6% RHA and varying RCC 15 percentages (5%, 7%, 9%, 11%) was based on previous optimization studies that identified these compositions as most effective in enhancing soil strength [26,27].

3.4 Stabilization Soil Sampling

In this study, soil samples were taken from a location with coordinates 6°58'48"S 107°26'08"E, Cililin area, West Bandung Regency, Indonesia. The research was conducted at the Soil Mechanics Laboratory, Department of Civil Engineering, Bandung State University of Technology. The rice husk ash used in this stabilization process was sieved using a No. 20 sieve**.** The mixture content in this test consisted of 6% rice husk ash (RHA) and 5%, 7%, 9% and 11% spent catalyst rcc 15 (RCC) from soft clay, followed by Compaction, Atterberg Limit, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) testing.

4. TEST RESULTS

The initial stage of this study involves collecting soft soil samples from Cililin, West Java. These soft soil samples will undergo index property testing, followed by stabilization with the addition of Rice Husk Ash (RHA) and Spent Catalyst RCC 15 (RCC) with 3 and 7 days of curing. The mixture percentages used in this study are based on previous research, with RHA at 6%, and RCC 15 varied at 5%, 7%, 9%, and 11%. The purpose of index properties testing is to determine the specific gravity, water content, unit weight, and Atterberg limits. This test aims to identify the characteristics of the soft soil based on its classification according to AASHTO and USCS standards [28]. The table below presents the results of the soft soil's index properties.

Table 3 Index Properties of Soft Soil

Index Properties	Symbol	Unit	Value
Water Content	w	%	41.48
Specific Gravity	Gs	-	2.591
Weight of Content	γ	kN/m^3	13.13
Atterberg Limit			
Liquid Limit	LL	%	59.38
Plastic Limit	PL	%	29.93
Plasticity Index	PI	%	29.45

Based on the data from the physical property tests, the soil is classified as type A-7-6 according to AASHTO standards. Under the USCS classification, the soil is identified as CH, indicating it is an inorganic clay with high plasticity or expansive clay [29].

4.1 Moisture Content and Density Relationship

Table 4 presents a summary of the compaction test results for each mixture proportion. The findings indicate a noticeable increase in the maximum dry density (MDD) and a decrease in the optimum moisture content (OMC) with the addition of spent catalyst rcc 15 to the mixture sample. A similar trend is observed when a constant 6% Rice Husk Ash (RHA) is incorporated into the specimens. Generally, the compaction curves for clay soils exhibit a bell-shaped pattern, as seen in the compaction test curve for soil soil and the soil mixture containing 11% spent catalyst rcc 15. Conversely, the introduction of RCC into the soil specimens resulted in a leftward shift of the compaction curves, a pattern typically associated with silt mixed with sand. This alteration in the compaction curve trends highlights the effectiveness of the admixtures used in the research[30]. A more detailed visualization of the curve comparisons is provided in Figure 2.

Table 4 The Average OMC and MDD of Mixture Variation

Variation	OMC (%)	MDD (g/cm^3)
Soft Soil	20.51	1.318
6 % RHA + 5% RCC	26.45	1.327
6 % RHA + 7% RCC	26.06	1.337
6 % RHA + 9% RCC	26.00	1.343
6 % RHA + 11% RCC	25.67	1.355

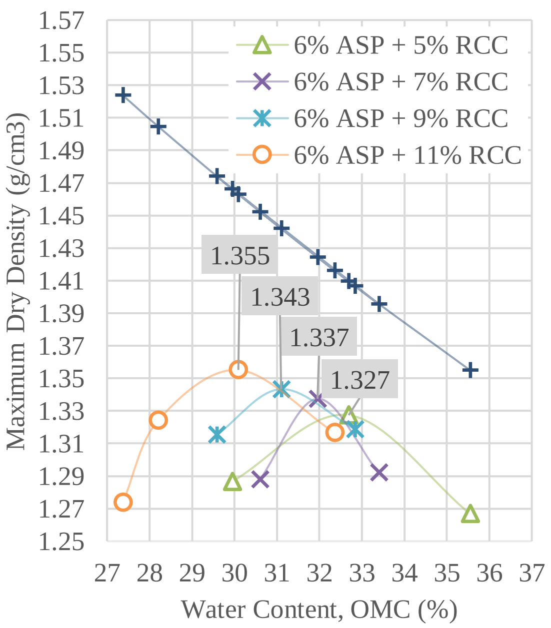

Fig. 3 The comparison of maximum dry density curves of stabilization soil

The graph displays the moisture-density curves for each mixture, plotting MDD against varying moisture contents. As the RCC content increases from 5% to 11%, the peak of each curve shifts slightly higher, indicating that the MDD improves as RCC content rises. This leftward and upward shift of the compaction curves reflects a typical response for clay stabilized with pozzolanic materials like RHA and RCC[9]. The highest MDD is observed at the combination of 6% RHA with 11% RCC, supporting the conclusion that increased RCC contributes to greater dry density. In summary, both the table and graph demonstrate that the addition of RHA and RCC ameliorate the compaction characteristics of soft clay, with 6% RHA and 11% RCC yielding the best results in terms of lower OMC and higher MDD. This improvement is consistent with the pozzolanic reaction that contributes to soil densification and strength.

4.2 Atterberg Limit

The plasticity index (PI) of soft clay measures the range of water content at which the soil displays plastic behavior, making it a critical property in geotechnical engineering. This value is determined by the difference between the soft clay's liquid limit (LL) and plastic limit (PL)[31]. The following table presents the results of physical property tests, specifically the Atterberg limits, for the original soil after stabilization with RHA and RCC 15.

Table 5 Atterberg Limit Test Result

Variation	LL	PL	PI
Soft Soil	59.38	29.93	29.45
6 % RHA + 5% RCC	54.67	26.45	28.22
6 % RHA + 7% RCC	52.50	26.06	26.44
6 % RHA + 9% RCC	51.68	26.00	25.68
6 % RHA + 11% RCC	51.23	25.67	25.55

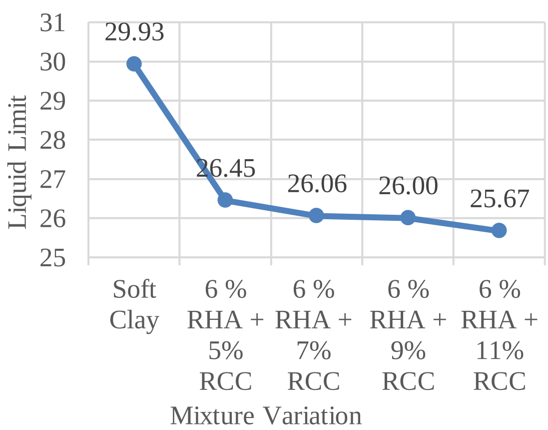

Fig. 4 Liquid limit graph

The figure above illustrates that adding rice husk ash and Spent Catalyst RCC 15 as stabilizing agents reduces the soil's liquid limit. This reduction occurs because the soil is mixed with silica compounds that exhibit pozzolanic properties. These properties promote cementation, increasing the size of soil particles and thereby decreasing the attractive forces between them.

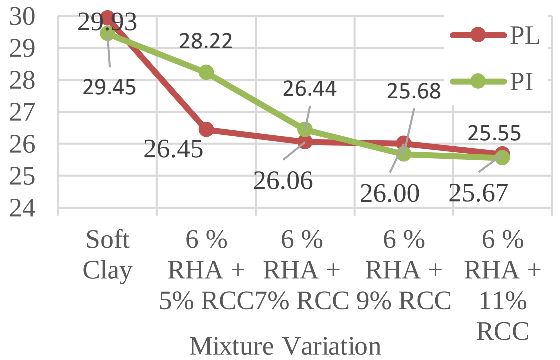

Fig. 5 Plastic Limit and Plasticity Index graph

The figure above illustrates that adding rice husk ash and Spent Catalyst RCC 15 as stabilizing agents reduces the soil's plastic limit. This reduction occurs because the soil is mixed with silica compounds that exhibit pozzolanic properties. These properties promote cementation, increasing the size of soil particles and thereby decreasing the attractive forces between them.

The figure above demonstrates that incorporating rice husk ash and spent catalyst RCC 15 as stabilizing materials lowers the plasticity index of the soil. A reduced plasticity index diminishes the soil's potential for swelling and shrinkage[32]. This effect is due to the hydration process of rice husk ash and spent catalyst RCC 15, which exhibit pozzolanic properties that strengthen the bonds between soil particles, creating more stable and rigid aggregates. When mixed with water, rice husk ash and RCC 15 form a paste that binds clay particles and fills the soil's pores. These filled pores become less permeable, enhancing the mixture's resistance to water absorption and thereby decreasing its plasticity.

4.3 Unconfined Compression Test (UCS)

The results of the unconfined compression test provide the values of unconfined compressive strengths (q_u) for the original soil and the variations of soil stabilized with rice husk ash (RHA) and spent catalyst RCC 15 with 3 days and 7 days of curing time. These results include the values of compressive strength (q_u) and c_u (shear strength values) for each mix variation, which can be found in the following table. The unconfined compressive strength (UCS) of the original soft clay was recorded at 0.040 MPa. As the proportion of spent catalyst RCC 15 (RCC) and rice husk ash (RHA) increased in the mixture, the compressive strength of the stabilized soil showed a significant improvement. This trend is clearly illustrated in Fig. 6, where both 3-day and 7-day curing periods exhibit a continuous increase in qu values with the addition of stabilizing agents.

Table 6 Unconfiend Compression Test Reuslt

Variation	3 Days q_u (MPa)	7 Days q_u (MPa)
Soft Clay	0.040	
6 % RHA + 5% RCC	0.078	0.106
6 % RHA + 7% RCC	0.133	0.137
6 % RHA + 9% RCC	0.133	0.180
6 % RHA + 9% RCC	0.179	0.217

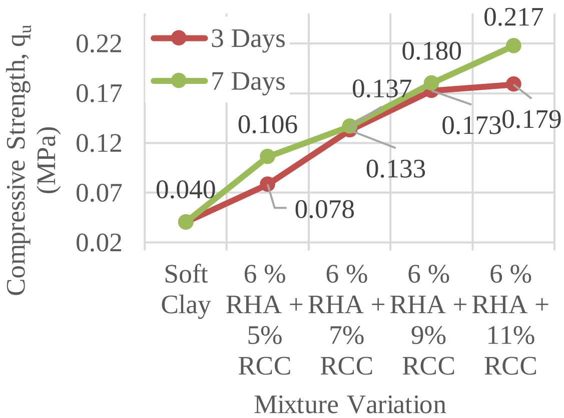

Fig. 6 Unconfined compression (UCS) graph

For the mixture containing 6% RHA and 11% RCC, the UCS reached its highest value of 0.217 MPa at 7 days of curing, demonstrating a substantial enhancement compared to untreated soil. The observed improvement in soil strength is primarily attributed to pozzolanic reactions and particle bonding mechanisms. The high silica content in RHA and the combination of silica, alumina, and iron in RCC react with calcium hydroxide in the soil, forming calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) compounds. These cementitious compounds reduce soil plasticity, enhance particle interlocking, and densify the soil structure, leading to increased compressive strength[33].

The trend in Fig. 6 also highlights that longer curing durations further enhance soil strength, particularly as pozzolanic reactions continue to develop over time. This confirms the effectiveness of RHA and RCC in stabilizing soft clay, making it a viable and sustainable solution for soil improvement in construction applications.

4.4 SEM Analysis

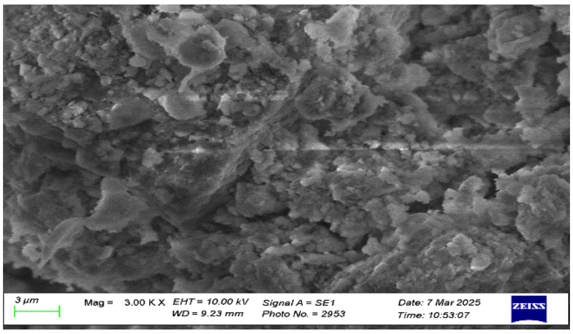

Fig. 7 Soft Clay Sample

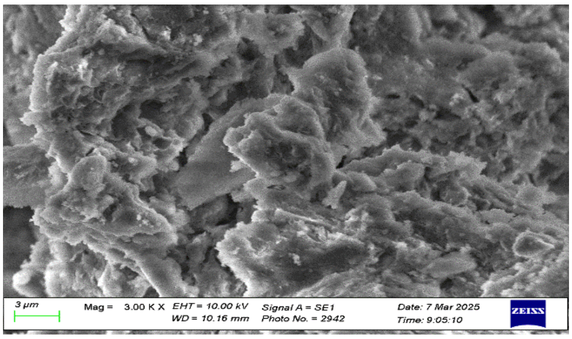

Fig. 8 Stabilization Sample (6% RHA + 11% RCC)

The SEM analysis demonstrates a significant transformation in soil microstructure before and after stabilization with Spent Catalyst RCC 15 (RCC) and Rice Husk Ash (RHA). The untreated soil exhibits medium to large pores, indicating a loose structure with substantial voids capable of retaining water and air, which contributes to its low density and high plasticity. However, after stabilization, the soil pores become more compact as pozzolanic reactions occur, facilitating the formation of calcium silicate hydrate (C-S-H) that acts as a binder between particles. This reaction enhances the overall soil structure, reducing voids and increasing interparticle bonding. The improved density and homogeneity observed in the SEM images align with laboratory test results, which indicate increased unconfined compressive strength (UCS) and a lower plasticity index (PI). These findings confirm that the addition of RCC and RHA effectively improves the mechanical properties of soft clay soil, making it more suitable for construction applications.

5. CONCLUSION

The Atterberg limit tests conducted on the original soil yielded a plasticity index (PI) of 29.45%. In contrast, the soil stabilized with 6% rice husk ash (RHA) and 11% spent catalyst RCC achieved a PI value of 25.55%, indicating a reduction in plasticity. This suggests that the addition of RHA and RCC effectively enhances soil stability by reducing its tendency to undergo volumetric changes. The pozzolanic properties of these stabilizing agents promote cementation reactions, leading to a more cohesive and structurally stable soil matrix. In the compaction test, the addition of RCC 15 and RHA improved the maximum dry density (MDD) while influencing the optimum moisture content (OMC). The original soft clay exhibited an OMC of 20.51% and an MDD of 1.318 g/cm³. With a fixed 6% RHA and increasing RCC 15 content from 5% to 11%, the MDD increased to 1.355 g/cm³, while the OMC slightly adjusted to 25.67%. This indicates that higher RCC 15 content enhances soil compaction, leading to better densification and improved load-bearing capacity. During the unconfined compressive strength (UCS) test, the untreated soft soil recorded a compressive strength of 0.040 MPa. However, stabilization with 6% RHA and 11% RCC resulted in a significant increase, reaching 0.217 MPa after 7 days of curing. This increase in UCS confirms that higher RCC 15 content enhances the binding properties of the soil, strengthening its internal structure through pozzolanic and cementitious reactions. The formation of calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) compounds within the soil matrix contributes to this improved mechanical performance.

Overall, the study findings confirm that RHA and RCC 15 significantly enhance the strength, compaction, and plasticity characteristics of soft clay. The optimal mixture of 6% RHA and 11% RCC 15 resulted in a 5.4-fold increase in UCS, a 13.2% reduction in PI, and improved MDD with lower OMC. These results highlight the suitability of RHA and RCC 15 for field applications, with potential for further optimization through extended curing durations and alternative mixing techniques in future studies.

6. ACKNOWLEDGMENTS

This research was provided by the Department of Civil Engineering at Politeknik Negeri Bandung, specifically through the Magister of Applied Infrastructure Engineering Study Program. The authors extend their gratitude to all parties who contributed to this research effort.

7. REFERENCES

[1] Jafer H, Majeed ZH, Dulaimi A. Incorporating of Two Waste Materials for The Use in Fine-Grained Soil Stabilization. Civil Engineering Journal (Iran) 2020;6:1114–23. https://doi.org/10.28991/cej-2020-03091533.

[2] Liu Y, Su Y, Namdar A, Zhou G, She Y, Yang Q. Utilization of Cementitious Material from Residual Rice Husk Ash and Lime in Stabilization of Expansive Soil. Advances in

Civil Engineering 2019;2019. https://doi.org/10.1155/2019/5205276.
[3] Yuliana L, Sarie F, Gandi S. Stabilisasi Tanah Lempung Menggunakan Serbuk Gypsum, Abu Sekam Padi, Dan Kapur. Spektrum Sipil 2022;9:151–9. https://doi.org/10.29303/spektrum.v9i2.228.
[4] Karami H, Pooni J, Robert D, Costa S, Li J, Setunge S. Use of Secondary Additives in Fly Ash Based Soil Stabilization for Soft Subgrades. Transportation Geotechnics 2021;29. https://doi.org/10.1016/j.trgeo.2021.100585.
[5] Fadilla N, Roesyanto. Pengujian Kuat Tekan Bebas (Unconfined Compression Test) Pada Stabilitas Tanah Lempung Dengan Campuran Semen Dan Abu Sekam Padi. 2017.
[6] Raman RS, Lavanya C, Revathi B, Nijhawan G, Yadav DK, Mohammad Q, Sethi VA. Optimization of RHA and Cement Proportion for Soil Stabilization. E3S Web of Conferences 2024;529. https://doi.org/10.1051/e3sconf/202452901015.
[7] Liu Y, Chang CW, Namdar A, She Y, Lin CH, Yuan X, Yang Q. Stabilization of Expansive Soil Using Cementing Material from Rice Husk Ash and Calcium Carbide Residue. Constr Build Mater 2019;221:1–11. https://doi.org/10.1016/j.conbuildmat.2019.05.157.
[8] Jiang X, Huang Z, Ma F, Luo X. Analysis of Strength Development and Soil–Water Characteristics of Rice Husk Ash–Lime Stabilized Soft Soil. Materials 2019;12:3873. https://doi.org/10.3390/ma12233873.
[9] Edora AB, Adajar MAQ. Strength And Permeability Characteristics Of Expansive Soil With Gypsum And Rice Husk Ash. International Journal of GEOMATE 2021;21:28–34. https://doi.org/10.21660/2021.88.gxi251.
[10] Hermawan T, Syahril. Kajian Perbaikan Subgrade Dari Tanah Ekspansif Menggunakan Spent Catalyst Rcc 15 Dan Abu Batok Kelapa Sawit. Jurnal Potensi 2016.
[11] Widianti A, Diana W, Rahmawati A, Wibowo DE. Combination of Coir Fiber Waste and Coir-Wood Ash for Expensive Clay Stabilitation. International Journal of GEOMATE 2023;25:230–7. https://doi.org/10.21660/2023.111.3976.
[12] Archibong G, Sunday EU, Akudike J, Okeke O. A Review Of The Principles And Methods Of Soil Stabilization. International Journal of Advanced Academic Research 2020;6.
[13] Kamaruddin FAB, Huat BBK, Anggraini V, Nahazanan H. Modified Natural Fiber on Soil Stabilization with Lime and Alkaline Activation Treated Marine Clay. International Journal of GEOMATE 2019;16:69–75. https://doi.org/10.21660/2019.58.8156.
[14] Saleh AR, Harwadi F. Stabilisasi Tanah Lempung Lunak Dengan Abu Sekam Padi (Rha) Dan Kapur (Caco3) Di Kampung Satu Kota Tarakan. Jurnal TEKNIK UBT 2017;1:1–6.
[15] Amalia, Setiawan Y, Tiyani L, Murdiyoto A. Effect Of Rice Husk Ash And Steel Fibers On Self-Compacting Concrete Properties. International Journal of GEOMATE 2023;25:130–7. https://doi.org/10.21660/2023.108.3677.
[16] Isberto CD, Labra KL, Landicho JMB, De Jesus R. Optimized preparation of rice husk ash (RHA) as a supplementary cementitious material. International Journal of GEOMATE 2019;16:56–61. https://doi.org/10.21660/2019.57.4628.
[17] Adeyanju E, Okeke CA, Akinwumi I, Busari A. Subgrade Stabilization using Rice Husk Ash-based Geopolymer (GRHA) and Cement Kiln Dust (CKD). Case Studies in Construction Materials 2020;13. https://doi.org/10.1016/j.cscm.2020.e00388.
[18] Almajed A, Moghal AAB, Nuruddin M, Mohammed SAS. Comparative Studies on the Strength and Swell Characteristics of Cohesive Soils Using Lime and Modified Enzyme-Induced Calcite Precipitation Technique. Buildings 2024;14. https://doi.org/10.3390/buildings14040909.
[19] David JM. Quantification Of Hydration Products In Rice Husk Ash (Rha)-Blended Cement Concrete With Crumb Waste Rubber Tires (Cwrt) & Its Correlation With Mechanical Performance. International Journal of GEOMATE 2022;23. https://doi.org/10.21660/2022.99.s8603.
[20] Hidalgo F, Saavedra J, Fernandez C, Duran G. Stabilization of Clayey Soil for Subgrade Using Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SCBA). IOP Conf Ser Mater Sci Eng 2020;758. https://doi.org/10.1088/1757-899X/758/1/012041.
[21] Jain A, Choudhary AK, Jha JN. Influence of Rice Husk Ash on the Swelling and Strength Characteristics of Expansive Soil. Geotechnical and Geological Engineering 2020;38:2293–302. https://doi.org/10.1007/s10706-019-01087-6.
[22] Pinasaing DB, Sompie O, Jansen F. Analisis Campuran Kapur-Fly Ash Dan Kapur-Abu Sekam Padi Terhadap Lempung Ekspansif.

Jurnal Ilmiah Media Engineering 2016;6:535–46.

[23] Brahmachary TK, Ahsan MK, Rokonuzzaman M. Impact of Rice Husk Ash (RHA) and Nylon Fiber on The Bearing Capacity of Organic Soil. SN Appl Sci 2019;1. https://doi.org/10.1007/s42452-019-0275-0.

[24] Ghorbani A, Salimzadehshooiili M. Dynamic Characterization of Sand Stabilized with Cement and RHA and Reinforced with Polypropylene Fiber. Journal of Materials in Civil Engineering 2019;31:1–24. https://doi.org/10.1061/(asce)mt.1943-5533.0002727.

[25] Sulistyowati T, Muchtaranda IH. Pengaruh Penambahan Spent Catalyst Terhadap Daya Dukung Tanah Lempung Ekspansif Yang Distabilisasi Dengan Fly Ash. Spektrum Sipil 2014;1:202–11.

[26] Gunarti ASS. Daya Dukung Tanah Lempung Yang Distabilisasi Dengan Spent Catalyst Rcc 15 Dan Kapur. Jurnal Bentang 2014;2.

[27] Adha I. Pemanfaatan Abu Sekam Padi Sebagai Pengganti Semen Pada Metoda Stabilisasi Tanah Semen. Jurnal Rekayasa 2011;15.

[28] Muntaha M, Fitrie RHA, Wahyuni F, Tajunnisa Y. The Use Of Alkaline Activators With High Calcium Fly Ash As Soft Clay Stabilization Materials. International Journal of GEOMATE 2023;25:9–17. https://doi.org/10.21660/2023.109.3286.

[29] Nsaif MH, Obaid A, Fattah MY. Examining The Swelling Potential Of Expansive Soil Containing Waste Paper Ash. International Journal of GEOMATE 2025;28:43–51. https://doi.org/10.21660/2025.126.4709.

[30] Hartono E, Diana W, Nugraha YS, Afzalurrahman M. Compaction Properties Of The Fly-Ash Based Geopolymer On Silt Soil. International Journal of GEOMATE 2024;26:19–26. https://doi.org/10.21660/2024.116.4262.

[31] Shukri AN, Azhar S, Tajudin A, Hakimi A, Nor M. Determination of Unconfined Compressive Strength and Atterberg Limit of Soft Clay by Stabilizing with Sodium Silicate and Biomass Silica in Batu Pahat. Journal of sustainable underground exploration 2021;1:20–4. https://doi.org/10.30880/jsue.2021.01.003.

[32] Pushpakumara BHJ, Mendis WSW. Suitability of Rice Husk Ash (RHA) with Lime as a Soil Stabilizer in Geotechnical Applications. International Journal of Geo-Engineering 2022;13. https://doi.org/10.1186/s40703-021-00169-w.

[33] Almajed A, Moghal AAB, Nuruddin M, Mohammed SAS. Comparative Studies on the Strength and Swell Characteristics of Cohesive Soils Using Lime and Modified Enzyme-Induced Calcite Precipitation Technique. Buildings 2024;14. https://doi.org/10.3390/buildings14040909.