

Mechanical Characteristics of High Plasticity Clay Stabilized Using Lime and Rice Husk Ash

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Article Information	ABSTRACT
Article History Received : June 02, 2026 Revised : June 25, 2026 Published : July 10, 2026	High-plasticity clay is a type of problematic soil due to its low bearing capacity, low unconfined compressive strength, and high shrinkage-swelling potential. Stabilization is one method for improving the soil's characteristics. The research was conducted through physical property testing of natural soil, including sieve analysis, atterberg limits, moisture content, bulk density, and specific gravity tests, as well as mechanical testing using the UCS method on natural soil and stabilized soil with three mixture variations, namely Variation 1 (5% lime + 4% RHA), Variation 2 (5% lime + 8% RHA), and Variation 3 (5% lime + 12% RHA). The natural soil had an average UCS value of 23.55 kPa, while Variation 1 increased to 95.51 kPa, Variation 2 reached 193.50 kPa, and Variation 3 reached 114.71 kPa. Variation 2 produced the highest UCS value among the variations. The UCS increased by approximately 722% at the optimum mixture of 5% lime + 8% RHA. This study demonstrates that the use of lime and RHA significantly improves the mechanical characteristics of high-plasticity clay.
Keywords: <i>High Plasticity Clay;</i> <i>Lime;</i> <i>RHA;</i> <i>UCS.</i>	

INTRODUCTION

High-plasticity clay is one of the problematic soil types because it has poor engineering characteristics, such as high shrinkage–swelling potential and low bearing capacity (Hayati & Budhi, 2025; Rodiyani et al., 2024; Sandi et al., 2022). His shrinkage–swelling potential is caused by the presence of active clay minerals, such as montmorillonite, which can absorb large amounts of water within their interparticle structure (Holt et al., 2023). These conditions often lead to structural damage, such as pavement cracking, foundation deformation, and slope failure (Liu et al., 2019). Due to the poor characteristics of this type of soil, ground improvement is necessary, one of which is soil stabilization.

In general, soil stabilization methods are classified into three types: mechanical, physical, and chemical stabilization (Sandi & Erwanto, 2025). Chemical stabilization is one of the most commonly used methods, which involves adding binders or certain chemical agents into the soil to modify its physical and mechanical properties through chemical reactions (Budhi & Maharani, 2025). In general, soil stabilization materials may originate from conventional materials such as cement and lime, industrial by-products (Almuaythir et al., 2024) such as fly ash (Alam & Alselami, 2024; Qiu et al., 2025) and ground granulated blast furnace slag, as well as eco-friendly binders such as bagasse ash (Nurmawati et al., 2026) and rice husk ash (Jiang et al., 2019; Zaika & Suryo, 2020).

Lime can improve soil strength through pozzolanic reactions that produce cementitious compounds, such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), thereby increasing bearing capacity and reducing soil plasticity (Jiang et al., 2019; Sipangkar et al., 2023). Meanwhile, rice husk ash (RHA) is an agricultural waste product rich in amorphous silica (SiO_2) and typically contains more than 70% silica (Eniarti et al., 2024). The addition of lime to the soil increases the pH, creating an alkaline condition that triggers cation exchange and flocculation among clay particles. This process causes the initially dispersed clay particles to agglomerate, resulting in reduced plasticity and improved soil structure stability (Shaji & Divya, 2024). In addition, lime contains calcium ions (Ca^{2+}) that react with silica (SiO_2) and alumina (Al_2O_3) present in both the soil and RHA, producing cementitious compounds such as Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH), which function as binding agents between soil particles. The formation of these compounds reduces the voids between particles, thereby increasing the soil's strength and stiffness. When RHA is mixed with lime, the amorphous silica contained in the RHA reacts with calcium hydroxide produced from lime hydration, resulting in the formation of additional CSH compounds. This reaction increases soil density, reduces porosity, and enhances the Unconfined Compressive Strength and bearing capacity of the soil. The addition of RHA up to its optimum content significantly improves the UCS; however, excessive addition may reduce soil strength due to ash particles that do not react optimally and instead behave as unbounded particles (MolaAbasi et al., 2022). The application of lime and RHA reduces the shrink-swell potential of clay soils. This effect is attributed to flocculation and cementation processes, which decrease the water-absorption capacity of clay particles and produce a denser, more stable soil structure that is more resistant to moisture fluctuations than untreated soil (Shaji & Divya, 2024). The use of RHA as a stabilization agent demonstrates that environmentally friendly pozzolanic materials can enhance soil mechanical properties while reducing the environmental impacts associated with conventional stabilization methods (MolaAbasi et al., 2022).

Several studies have shown that adding lime and Rice Husk Ash (RHA) improves the mechanical properties of clay soils (Ayodele et al., 2022; Chen et al., 2022; Liu et al., 2019; Muthu Lakshmi et al., 2021; Pushpakumara & Mendis, 2022; Raja et al., 2022; Syaputra et al., 2022). For example, a mixture of 4% lime and 20% RHA in clayey sand achieved the highest Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) after three days of curing (Muthu Lakshmi et al., 2021). Another study found that 20% lime and 10% RHA increased UCS by 54.05%, improved the internal friction angle by 60.48%, and reduced the plasticity index by 56.67% after 28 days (Pushpakumara & Mendis, 2022). Similarly, combining 10% RHA with 15% lime sludge in expansive clay reduced the liquid limit and plasticity index, while significantly increasing UCS and CBR compared to untreated soil (Raja et al., 2022).

This study identifies a research gap by applying various mixture variations to high-plasticity clay obtained from Dusun Sumberjo, Banyuwangi. This study aims to analyze the effects of lime and Rice Husk Ash (RHA) on the mechanical characteristics of high-plasticity clay, with a focus on the unconfined compressive strength (UCS). Initial testing was conducted to identify the physical properties and soil classification based on particle size distribution and Atterberg limits. The stabilization process employed three mixtures of lime and RHA: 5% lime + 4% RHA, 5% lime + 8% RHA, and 5% lime + 12% RHA. UCS testing was performed to evaluate changes in the soil's mechanical characteristics after stabilization. The results of this study are expected to contribute to the development of knowledge regarding the utilization of pozzolanic materials and agricultural waste as stabilizing agents for high-plasticity clay soils. In addition, this method may serve as a more economical, environmentally friendly, and sustainable alternative for soil improvement to enhance soil bearing capacity.

RESEARCH METHODS

Soil Samples and Types of Testing

The clay soil used in this study was obtained from Dusun Sumberjo, Banyuwangi Regency. The soil samples used were disturbed, collected with a hoe at a depth of 60–80 cm below the ground surface. The tests conducted included physical and mechanical property tests of the

soil samples. The physical property tests consisted of sieve analysis (BSN, 2008e), Atterberg limits tests (BSN, 2008c, 2008d), moisture content test (BSN, 2008b), specific gravity test (BSN, 2008a), and bulk density test (BSN, 1994), using natural soil samples without any stabilization additives, with the number of samples presented in **Table 1**. The physical property tests were carried out to determine the soil's initial condition and classify the soil type based on particle-size distribution and plasticity characteristics.

Table 1. Number of Samples for Physical Properties

No	Type of Test	Number of Samples	Sample Weight (grams)
1.	Sieve Analysis	1	500
2.	Liquid Limit	4	200
3.	Plastic Limit	3	100
4.	Moisture Content	3	100
5.	Specific Gravity	3	150
6.	Bulk Density	3	200

The Unified Soil Classification System (USCS) was employed to classify soil types and characterize the research samples. The USCS utilizes two primary parameters: particle-size distribution and soil plasticity characteristics. Particle-size distribution was assessed through sieve analysis, while plasticity characteristics were evaluated using Atterberg limit tests, specifically the liquid limit (LL) and plastic limit (PL). The initial classification stage determined the soil group by measuring the percentage of material passing the No. 200 sieve (0.075 mm). Soils with less than 50% passing were classified as coarse-grained, while those with more than 50% passing were classified as fine-grained. For fine-grained soils, further classification was based on LL and PI values, utilizing the plasticity chart in the USCS system, as shown in **Figure 1**.

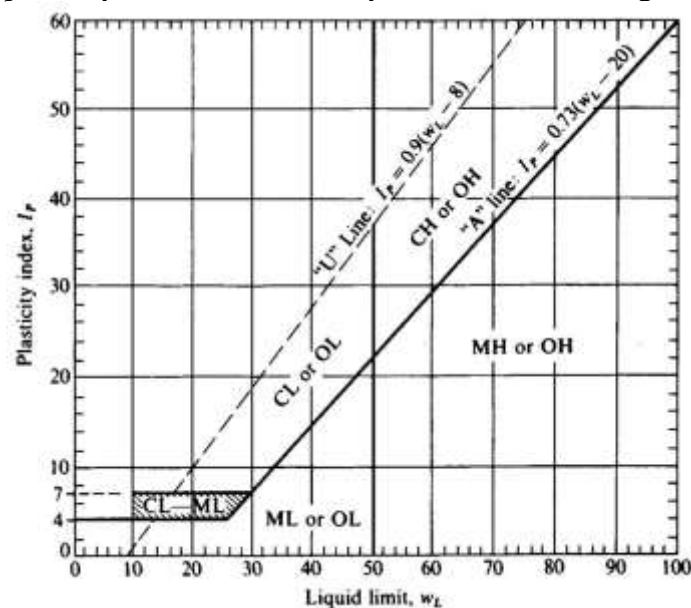


Figure 1. Casagrande Plasticity Chart

Stabilization Mixtures

The mechanical property test used in this study was the unconfined compressive strength (UCS) test (BSN, 2012). Mechanical soil testing aims to determine the behavior and bearing capacity of the soil under loading conditions. Each test used three samples: natural soil and soil mixed with stabilization materials, as presented in **Table 2**. The testing procedure comprised material preparation, mixing, curing, specimen preparation and testing, and data analysis. Soil samples were air-dried at room temperature to reduce initial moisture content. After drying, the soil was gently pulverized to separate particles while preserving their original characteristics. The pulverized soil was subsequently sieved through a No. 4 sieve (4.75 mm) to ensure a uniform particle-size distribution before mixing with stabilization materials.

The stabilization materials used in this study were lime and rice husk ash (RHA). The soil weight for each specimen was determined from the volume of the molding ring used in the UCS test. The amounts of lime and rice husk ash were adjusted according to the percentage variations used: 5% lime + 4% RHA, 5% lime + 8% RHA, and 5% lime + 12% RHA. All clay soil samples mixed with the stabilization materials were cured for 24 hours. The curing process facilitates the reaction between lime, RHA, and soil minerals.

Table 2. Number of Samples for Unconfined Compressive Strength

No	Code	Description	Number of Samples	Weight of Lime (grams)	Weight of RHA (grams)	Weight of Soil (grams)
1	A	Natural Soil	3	-	-	350
2	B	Variation 1 (lime 5%+RHA 4%)	3	17,5	14,0	318,5
3	C	Variation 2 (lime 5%+RHA 8%)	3	17,5	28,0	304,5
4	D	Variation 3 (lime 5%+RHA 12%)	3	17,5	42,0	290,5

After the curing process, the soil mixtures were molded into test specimens and subsequently subjected to the UCS test. A vertical axial load is applied at a constant rate until the test specimen fails. Throughout the loading process, both the load and the corresponding axial deformation are continuously recorded. The axial stress is then calculated using the following equation:

$$\sigma = \frac{P}{A}$$

with: σ = axial stress (kPa), P = axial load (kN), A = area of the test specimen (m²)

Since there is a change in area during the loading process, the corrected area can be calculated based on the change in axial strain:

$$A_c = \frac{A_0}{1 - \varepsilon}$$

with: A_c = corrected area (m²), A_0 = initial area (m²), ε = axial strain (%)

The UCS value is determined from the maximum stress attained before or at the moment the test specimen fails. The UCS test data, specifically the relationship between stress and strain, was analyzed to determine the peak stress value for each test specimen. Three test specimens were used for each mix variation, so the final UCS value was calculated as the average of the three test results. In addition to the average value, statistical analysis including standard deviation and coefficient of variation (CV) was performed to evaluate the degree of variation and consistency of the test results.

RESULTS AND DISCUSSION

Result of Soil Physical Properties Testing

The sieve analysis test aims to determine the soil particle size distribution as a basis for soil classification. Based on **Figure 2**, the percentage passing the No. 200 sieve (0.075 mm) is 50.4%, indicating that the soil is predominantly composed of fine particles. According to the Unified Soil Classification System (USCS), soils with more than 50% passing the No. 200 sieve are categorized as fine-grained soils, which may be classified as clay or silt depending on the Atterberg limits values (Das & Sobhan, 2018).

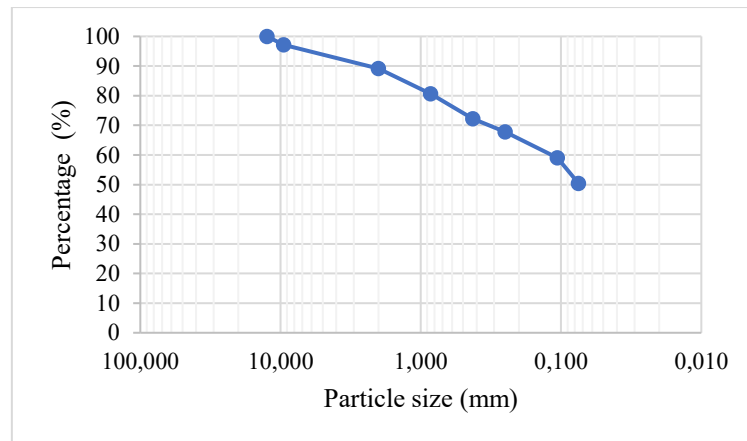


Figure 2. Sieve Analysis Graph

Based on **Figure 3**, the liquid limit graph, which represents the relationship between moisture content and the number of blows, produced a logarithmic regression line with the equation $y = -11.95\ln(x) + 103.36$. The liquid limit was obtained at $N = 25$ blows, resulting in a value of 64.89%. This value indicates that the soil sample belongs to the high-plasticity soil category.

The relationship curve between moisture content and the number of blows shown in **Figure 3** exhibits a consistent logarithmic trend: the greater the number of blows required to close the groove, the lower the soil moisture content. This behavior is consistent with the fundamental principle of the Casagrande method, which defines the liquid limit as the moisture content corresponding to a specific energy condition that produces 25 blows (Hrubesova et al., 2016; Kelly, 2021; Vardanega et al., 2019).

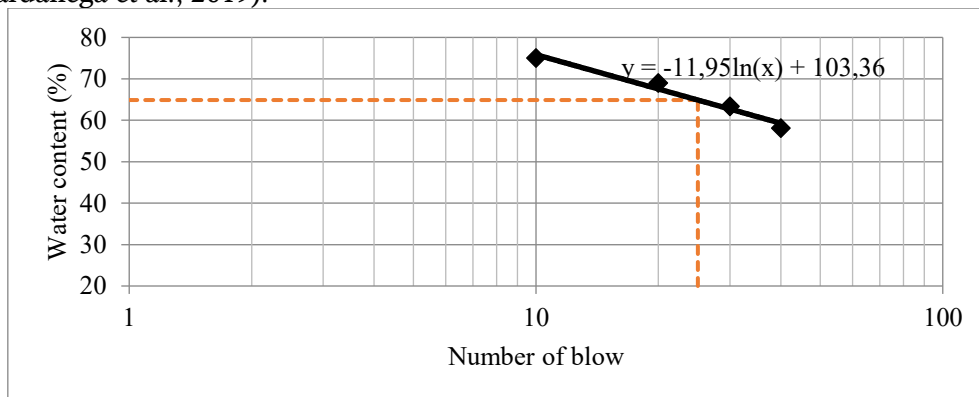


Figure 3. Liquid Limit Graph

The results of the physical properties tests of the soil, including moisture content, liquid limit, plastic limit, plasticity index, specific gravity, and bulk density, are shown in **Table 3**.

Table 3. Characteristics of Natural Soil

Parameter	Value
Moisture Content, W (%)	61,29
Liquid Limit, LL (%)	64,89
Plastic Limit, PL (%)	41,67
Plasticity Index, PI (%)	23,23
Specific Gravity	2,70
Bulk Density (gr/cm ³)	1,17

Source: Analysis (2026)

Based on **Table 3**, the test results showed a moisture content of 61.29%, a liquid limit of 64.89%, a plastic limit of 41.67%, and a plasticity index of 23.23%. These values indicate that the investigated soil belongs to the fine-grained, high-plasticity category. In general, soils with a liquid

limit (LL) greater than 50% are classified as high-plasticity silt (MH) according to the Unified Soil Classification System (USCS).

The plasticity index (PI) value of 23.23% indicates that the soil possesses high plasticity. This condition is influenced by clay minerals and soil structure, with the presence of active clay minerals, such as montmorillonite, often increasing LL and PI values PI (Bhavya & Nagaraj, 2025; Widjaja & Kurniawan, 2020). The moisture content value (61.29%), which is close to the liquid limit value (64.89%), indicates that the soil is in a condition approaching the plastic-liquid state.

Results of Soil Mechanical Properties Testing

Based on **Figure 4**, the three natural soil samples exhibited strain values of approximately 4–5% and stress values ranging from 23.49 to 23.58 kPa, indicating that the soil has relatively low unconfined compressive strength. This suggests that the soil is soft and has low bearing capacity.

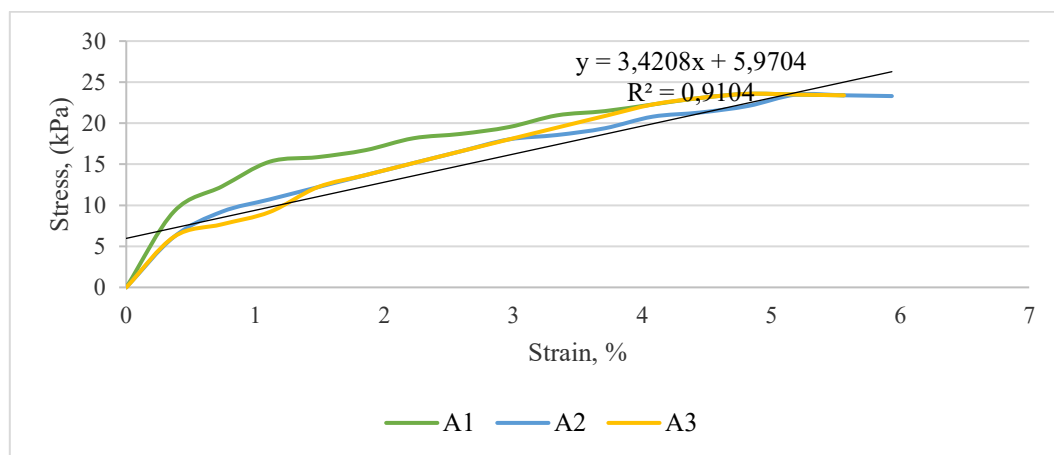


Figure 4. UCS Graph of Natural Soil

Based on **Figure 5**, a significant change in the soil's mechanical behavior is observed after stabilization with lime and rice RHA. The natural soil reached a maximum stress of approximately 23.488–23.580 kPa at a strain of about 4–5%, whereas the stabilized soil in Variation 1 showed an increase in maximum stress to approximately 95.119–95.916 kPa at a strain of about 10–12%. These results indicate that the stabilization process increased the UCS by more than 3 times compared to the soil's initial condition.

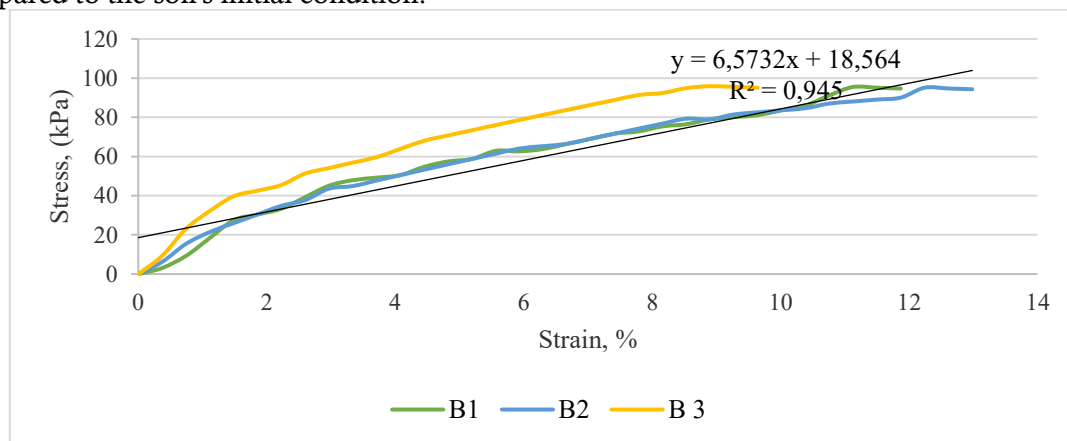


Figure 5. UCS Graph of Variation 1

Based on **Figure 6**, the stabilized soil in Variation 2 exhibited a higher increase in stress values compared to both the natural soil and Variation 1. The stress values increased with increasing strain, reaching a maximum of approximately 192.955–193.771 kPa at strains of about 11–13%. These results indicate that the stabilization process increased the UCS by more than 8 times compared to the soil's initial condition.

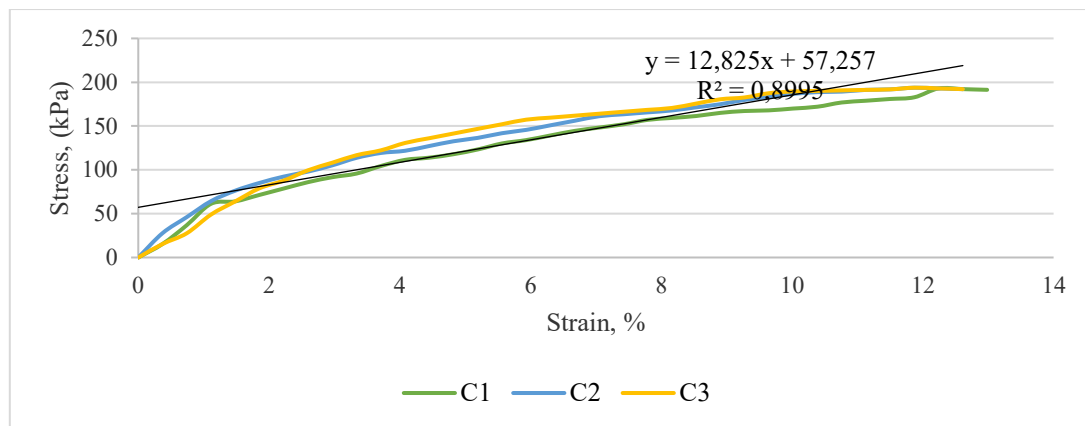


Figure 6. UCS Graph of Variation 2

Based on **Figure 7**, the stabilized soil in Variation 3 showed higher stress values than the natural soil; however, it showed lower stress values than Variation 2. The three samples in Variation 3 exhibited a gradual increase in stress with increasing strain, reaching a maximum of approximately 104.805–119.903 kPa.

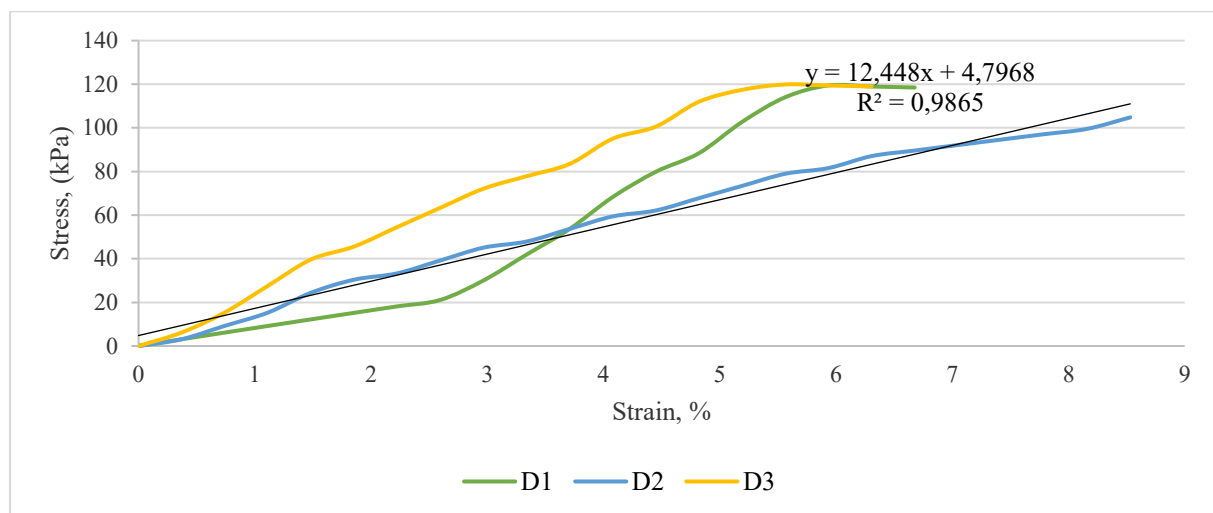


Figure 7. UCS Graph of Variation 3

Based on **Figure 8** and **Table 4**, the comparison of the UCS values shows that the stabilization process using lime and RHA had a highly significant effect on improving the mechanical characteristics of high-plasticity clay. The UCS values of the natural soil samples (A1, A2, and A3) ranged from 23.488 to 23.580 kPa. These values indicate that the soil possesses low strength and can be classified as soft soil with poor bearing capacity (Agustawijaya, 2007). The low UCS values of the natural soil are associated with its high clay content and soil plasticity, which result in weak interparticle bonding and make the soil susceptible to deformation with changes in moisture content (Das & Sobhan, 2018).

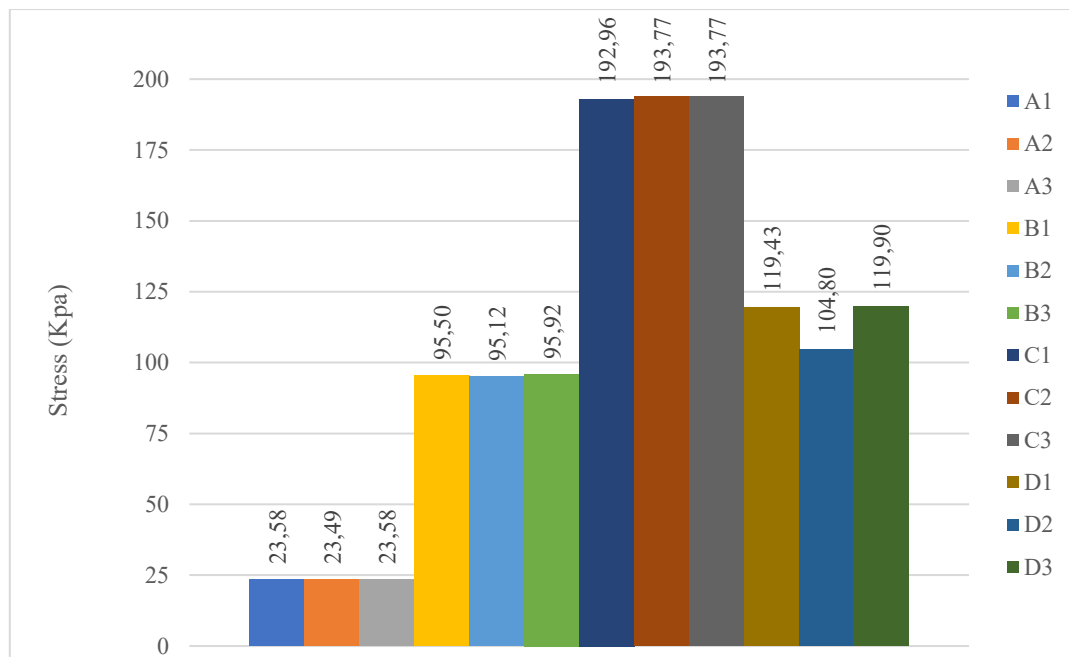


Figure 8. UCS Comparison between Natural Soil and Lime-Rice Husk Ash Stabilized Soil

After stabilization in Variation 1 using a mixture of 5% lime and 4% RHA (B1, B2, and B3), the UCS values increased to approximately 95.119–95.916 kPa. This improvement indicates that the stabilization process had initiated effective pozzolanic reactions that enhanced soil structure (Basha et al., 2005). In Variation 2, using a mixture of 5% lime and 8% RHA (C1, C2, and C3), the UCS values further increased to approximately 192.955–193.771 kPa. This variation exhibited the highest UCS values among all variations and can therefore be considered the optimum composition in this study. The substantial increase in strength indicates that the pozzolanic reactions occurred more effectively compared to Variation 1. Increasing the pozzolanic material content up to its optimum condition can accelerate the formation of cementitious products, thereby significantly improving soil strength and stiffness (Cong et al., 2014; Ma et al., 2020; Srilatha & Praveen, 2020). A study found that the formation of CSH and CAH compounds can reduce the voids between soil particles, resulting in a denser, more stable soil structure (Ahmad et al., 2025).

Meanwhile, in Variation 3, using a mixture of 5% lime and 12% RHA (D1, D2, and D3), the UCS values ranged from 104.805 to 119.903 kPa. Although these values were still higher than those of the natural soil and Variation 1, they were lower than those of Variation 2. This condition indicates that excessive addition of rice husk ash does not always result in greater improvement in soil strength. Excessive use of pozzolanic materials may cause an imbalance in the silica-to-calcium ratio, leading to less effective cementation reactions (Budi et al., 2002; James & Pandian, 2016). As a result, the formation of cementitious compounds is suboptimal, resulting in reduced soil strength. In the study conducted by (Liu et al., 2019), soil stabilization was carried out using a combination of lime and RHA on clay soil, with a lime content of 4% and RHA contents ranging from 10–20% by dry soil weight. The results showed that adding RHA to the lime-stabilized mixture improved the UCS and CBR values compared with untreated soil. The relatively high RHA content still enhanced soil strength, which was attributed to the appropriate lime composition and favorable reaction conditions. Similar findings were reported by (Pushpakumara & Mendis, 2022), who found that combining calcium-rich materials with RHA resulted in a significant improvement in strength. However, in the present study, increasing the RHA content up to 12% resulted in a decrease in UCS compared to the 8% RHA variation. The reduction in strength observed in variation 3 may be attributed to the amount of silica contained in RHA exceeding the available calcium supplied by lime for the formation of cementitious products. Under these conditions, some RHA particles may not have undergone an optimal pozzolanic reaction and may have acted only as fillers, without forming strong bonds. Consequently, the formation of calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H)

compounds did not increase proportionally, resulting in a soil structure that was not stronger than that obtained in the optimum mixture.

Table 4. UCS Values between Natural Soil and Lime RHA-Stabilized Soil

No	Code	UCS Values (Kpa)	Mean	Standard Deviation (SD)	Coefficient of variation (CV)
1	A1	23,580	23,549	0,053	0,225
	A2	23,488			
	A3	23,580			
2	B1	95,499	95,512	0,399	0,418
	B2	95,119			
	B3	95,916			
3	C1	192,955	193,499	0,471	0,243
	C2	193,771			
	C3	193,771			
4	D1	119,432	114,713	8,584	7,483
	D2	104,805			
	D3	119,903			

Based on **Table 4**, all UCS test variations exhibited relatively small standard deviations compared to the average UCS. Standard deviation (SD) values ranged from 0.053 to 8.584 kPa, while coefficient of variation (CV) values ranged from 0.225 to 7.483%. All CV values were below 10%, which indicates low data variability and strong repeatability. The natural soil variation showed the lowest CV of 0.225%, indicating a highly uniform distribution of data among specimens. In variation 2, a CV of 0.243% indicates that the optimum mixture produced highly stable strength behavior among the tested specimens. In contrast, variation 3 exhibited the highest CV at 7.483%. This increased data variability may be attributed to the higher RHA content in the mixture, which could cause less uniform pozzolanic reactions and less consistent cementitious bonding throughout the specimens. However, this CV value remains within the acceptable range (<10%), indicating that the test results are consistent.

CONCLUSION

Stabilizing high-plasticity clay with lime and RHA enhances soil mechanical properties through pozzolanic reactions and alterations to soil particle structure. The findings show that RHA, when used at its optimum content, yields the highest increase in Unconfined Compressive Strength (UCS). In contrast, excessive RHA addition diminishes stabilization effectiveness due to an imbalance in the calcium-to-silica ratio during cementitious compound formation. The mixture containing 5% lime and 8% RHA was identified as the optimal composition, as it resulted in the most significant improvement in soil mechanical characteristics among the tested variations. Employing lime and RHA offers a cost-effective, environmentally sustainable alternative for soil stabilization, enhancing the bearing capacity of subgrade soils in civil engineering and transportation infrastructure projects while supporting the beneficial reuse of agricultural waste in construction.

A limitation of this study is that the curing period was limited to 24 hours. Therefore, longer curing periods, such as 7, 14, and 28 days, are recommended to better understand the development of pozzolanic reactions and the long-term improvement in soil strength. In addition, future studies should consider conducting other geotechnical tests, such as the California Bearing Ratio (CBR), direct shear strength, consolidation, permeability, and durability tests under wetting-drying cycles. Furthermore, microstructural analyses using SEM, XRD, or FTIR are recommended to identify the mechanism of cementitious compound formation and to provide a deeper understanding of soil structural changes induced by the stabilization process.

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