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## STRENGTH IMPROVEMENT OF SOFT CLAY STABILISED WITH RICE HUSK ASH AND RCC-15 SPENT CATALYST BASED ON UNCONFINED COMPRESSIVE STRENGTH PERFORMANCE (UCS)

Esron Padiri<sup>1\*</sup>, Syahril S<sup>1</sup>, Juang A<sup>2</sup>

<sup>1\*</sup>) Department of Civil Engineering, Bandung State Polytechnic, Bandung.  
Email Penulis Korespondensi : [esronpadiri@gmail.com](mailto:esronpadiri@gmail.com)  
085559405659

<sup>2</sup>) Department of Civil Engineering, Indonesia University of Education, Bandung  
Email: [akbardien@upi.edu](mailto:akbardien@upi.edu)

### ABSTRACT

This study evaluates the effect of combining 12% rice husk ash (RHA) with varying percentages of RCC-15 spent catalyst (7%, 9%, 11%, and 13%) on the engineering properties of soft clay soil obtained from Cililin. Laboratory tests were conducted, including physical property characterization, compaction tests, and unconfined compressive strength (UCS) tests with curing periods of 0, 3, 7, and 14 days. The results show that the addition of RHA and RCC-15 improves soil compaction characteristics, indicated by an increase in maximum dry density and a reduction in optimum moisture content. Furthermore, the UCS values increased significantly with higher RCC-15 content and longer curing periods, reaching values between approximately 1.57 and 3.66 kg/cm<sup>2</sup> at 14 days. These improvements are attributed to mechanical densification and pozzolanic reactions between the stabilizing agents and soil minerals. This study emphasizes the synergistic application of agricultural and industrial waste materials for local soil stabilization, indicating that the combined use of rice husk ash and RCC-15 spent catalyst can enhance the engineering performance of soft clay while supporting sustainable and resource-efficient ground improvement practices.

**Keyword:** rice husk ash, RCC-15 mixture, unconfined compressive strength (UCS), soft clay soil

### 1. INTRODUCTION

Soft clay soils in active seismic zones are susceptible to permanent deformation, which significantly increases the risk of structural failure. Soil from the Cililin area represents this condition, as it is classified as high-plasticity clay with a liquid limit (LL) of approximately 62.2% and a plasticity index (PI) of 30.2%. The natural moisture content (37.9%) exceeds the optimum moisture content for compaction (OMC = 28.4%), resulting in a low maximum dry density (MDD = 1.29 g/cm<sup>3</sup>). In addition, the unsoaked CBR value of only 2.5% indicates very low bearing capacity, making the soil unsuitable for use as a subgrade without improvement [1] [2], [3], [4].

Rice husk ash (RHA) has been widely reported as an effective pozzolanic material due to its high content of amorphous silica (SiO<sub>2</sub>), which reacts with calcium to form cementitious compounds such as calcium silicate hydrate [5], [6], [7]. Spent catalyst RCC-15 contains calcium oxide (CaO) and other oxides that can act as a calcium source or micro-filler, suggesting a potential synergistic effect when combined with RHA [11]. However, studies investigating the combined use of RHA (e.g., 12%) with varying RCC-15 contents on the unconfined compressive strength (UCS) of soft clay soils, particularly those with characteristics similar to Cililin soil, remain limited.

Therefore, this study aims to evaluate the effect of combining RHA with varying percentages of RCC-15 on the UCS of soft clay soil obtained from the Cililin area through a series of laboratory tests. The

study is expected to provide empirical data for local soil stabilisation design and support the sustainable utilisation of agricultural and industrial waste materials.

### 1.1. Soft clay soil properties and UCS relevance

The mechanical properties of clay soil are greatly impacted by moisture content, density, and mineralogical composition. [12], [13]. High moisture content, associated with problematic soft soil conditions, causes significant deformation and weak engineering properties[14]. Samples with low dry density (high initial void ratio) tend to exhibit insignificant unconfined compressive strength (UCS)[15].

The type of clay mineral, such as bentonite (montmorillonite) or kaolin (kaolinite), determines the specific surface area (SSA). Clay minerals affect index properties (i.e., plastic limit and liquid limit) as well as mechanical behaviour such as strength and stiffness[16]. The behaviour of clay soil is highly dependent on the type of clay minerals it contains[13].

Grain structure (fabric) or aggregation affects macroscopic strength performance because the strengthening mechanism involves microstructure and chemistry[16]. The formation of flocculated structures can occur through the adsorption of calcium ions ( $\text{Ca}^{2+}$ ) onto the surface of clay particles, forming larger clumps[17]. Crystalline cementation products are formed through pozzolanic reactions and  $\text{Ca}^{2+}$  ion diffusion, providing a significant bridging or cementation effect on the final strength[14].

### 1.2. Rice husk ash (RHA)

The high reactivity of RHA is due to its high silica content in the form of non-crystalline or amorphous silica, and highly reactive RHA is obtained when rice husks are burned under controlled conditions[18]. Burning rice husks in the temperature range of 600–700 °C produces amorphous silica[19], [20]. RHA burned at high temperatures (800–1000 °C) was found to contain cristobalite and quartz phases[21].

Reactivity is generally increased by improving the fineness of RHA; therefore, reducing its particle size is one of the most common methods for increasing pozzolanic activity[18]. Post-combustion grinding is recommended to remove agglomeration and increase pozzolanic activity[22].

RHA is an ideal pozzolanic material because it contains a large amount of active silica[23]. However, RHA cannot be used alone due to its lack of cementing properties and must be combined with a binder, such as lime or cement, and its effectiveness depends on the availability of  $\text{Ca}(\text{OH})_2$ , which reacts with  $\text{SiO}_2$  to produce C–S–H[24], [25].



Source: Prepared by the authors.

**Figure 1.** Rice husk ash (RHA)

### 1.3. Spent Catalyst RCC-15

The role of spent catalysts such as Residium Catalytic Cracking 15 (RCC-15) as a stabilising agent is to improve the physical and mechanical properties of soft clay soil, because it is industrial waste from the

petroleum processing process that contains silica oxide, alumina, and ferrous oxide, making it pozzolanic and suitable for use as a binder agent. Its addition can reduce the percentage of clay particles, which then changes the plastic limit and reduces the plasticity index (PI) due to a decrease in soil moisture content. These changes in physical properties increase compressive strength ( $q_u$ ) through a pozzolanic reaction between silicates and aluminates with clay minerals, causing the dominant elements of the spent catalyst to fill the silica and gibbsite sheets to form stable minerals. However, this increase in soil stability is only optimal at a certain RCC-15 content and decreases again if the dosage is added excessively, indicating a limit to the effectiveness of using this stabilising material [3], [4], [26].



Source: Prepared by the authors.

**Figure 2.** RCC-15

## 2. RESEARCH METHOD

This research methodology describes the systematic steps used to assess the effectiveness of adding RHA and RCC-15 in increasing the shear strength of clay soil. To test the effect of these two stabilising materials on the geotechnical properties of soil, this study applied a structured laboratory-based experimental approach, including sample selection, soil material preparation, a series of laboratory tests, and data processing and interpretation.

### 2.1. Soil Sampling Location

The sampling area, comprising rice fields and residential yards west of the village center, is indicated on the research location map with red markers. This location is easily accessible for field activities due to its proximity to the main road and service facilities along it. The soil conditions, consisting of wet clay layers and rice fields, indicate that the clay soil is soft and suitable for laboratory testing. The purpose of selecting this point is to show the actual field conditions in Cililin that often cause problems with pavement and foundations. In the future, the results of stabilization testing with RHA and RCC-15 can be applied to comparable local conditions.



Source: Prepared by the authors.

**Figure 3.** Research location

## 2.2. Sample Variations

Table 1 shows the percentage of additives in each treatment variation (Initial Soil, C1–C3) for RHA and RCC-15.

**Table 1.** Sample Variations

Variasi	RHA	RCC-15
Initial Soil	0 %	0 %
C1	12 %	7 %
C2	12 %	10 %
C3	12 %	13 %

Source: Prepared by the authors.

## 2.3. Index Properties Test

Preliminary testing was carried out by characterising the properties of the soil in each test specimen variation. The tests performed were as follows:

- a. Moisture content: Determined according to standard laboratory procedures using the oven drying method to obtain the water content of the sample; this measurement is useful for evaluating changes in water retention capacity before and after stabilisation treatment.
- b. Specific gravity: Measured to assess the relative mass density of soil to water; this parameter is important in understanding the internal structure and density level of the soil.
- c. Atterberg limits: Liquid limit, plastic limit, and plasticity index were determined to evaluate the consistency and plasticity of the soil; the results of this test were needed to assess the effect of stabiliser addition on the working properties and plasticity behaviour of clay soil.

## 2.4. Soil Classification

Soil classification is important in geotechnical engineering because it provides a framework for interpreting the physical and mechanical properties of soil that are relevant to the design and execution of structures. The two most commonly used systems are USCS and AASHTO, each developed for different purposes but both relying on particle size and plasticity.

USCS divides soils into two main categories: coarse-grained gravel (G) and sand (S) when <50% by weight of the sample passes a No. 200 sieve; and fine-grained silt (M), clay (C), and high organic material (PT) when  $\geq 50\%$  passes a No. 200 sieve. USCS combines grain size curves and plasticity parameters (liquid limit, plasticity index) for subclassification that reflects engineering behavior (bearing capacity, permeability, shrinkage/swelling potential).

AASHTO (Public Roads Administration, 1929) was designed for the evaluation of subgrades and pavements, grouping soils into A-1 to A-7. Groups A-1–A-3 are generally coarse-grained with a fine fraction  $\leq 35\%$ , while A-4–A-7 are dominated by a fine fraction ( $>35\%$ ). The main criteria include particle size and plasticity index (silt:  $PI \leq 10$ ; clay:  $PI \geq 11$ ), as well as recording the percentage of coarse rock ( $>75$  mm) removed.

Practically, use USCS for general geotechnical analysis (foundations, slope stability, soil-structure interaction) and AASHTO when focusing on pavement performance; technical reports often include both classifications to facilitate cross-application interpretation.

## 2.5. Unconfined Compression Strength Test (UCS)

The Unconfined Compressive Strength (UCS) test is conducted by applying axial loading to cohesive soil samples until failure occurs without applying lateral pressure, thereby obtaining the UCS, which is often used to estimate undrained shear strength. This test is relevant for determining the short-term mechanical resistance of soil and assessing the effect of stabilisation treatment on bearing capacity. The UCS test in this study was carried out on test specimens that had been soaked for 0, 3, 7, and 14 days to observe changes in compressive strength due to soaking time and the addition of stabilising agents. Drying of stabilized soil specimens is carried out in closed and humid conditions: after the soil samples

are mixed with chemical stabilizing agents, each specimen is placed into a plastic bag and sealed tightly to maintain humidity so that the water in the mixture does not evaporate excessively, so that the reaction between the soil and the additional materials can proceed more evenly.

### 3. RESULTS AND DISCUSSION

#### 3.1. Index Properties Test

Table 2 presents changes in soil index properties due to the stabilization of soft clay soil using rice husk ash (RHA) and spent catalyst RCC-15 under C3 conditions. The particle density (Gs) increased from 2.68 in the initial soil to 2.82 in C3, indicating a change in the composition of the solid phase of the soil. This increase indicates that the stabilization material contributes to the density of soil grains through filling voids or binding between particles, thereby modifying the mineralogical characteristics and microstructure of the soil.

More significant changes were observed in the Atterberg limit parameters. The liquid limit (LL) decreased from 59.10% to 41.79%, while the plastic limit (PL) decreased from 25.75% to 22.19%. The decrease in LL indicates a reduction in the soil's ability to absorb and retain water under plastic to liquid conditions, while the decrease in PL reflects a change in the plastic behavior limit towards a semi-solid condition. The combination of these two changes results in a significant decrease in the plasticity index (PI) from 33.35% to 19.60%, which indicates a narrowing of the soil's plasticity range.

Overall, the data in Table 2 show that stabilization with ASP and RCC-15 is effective in reducing the plasticity of soft clay soils. The decrease in PI indicates a reduction in the dominance of plastic behavior and soil sensitivity to changes in moisture content, so that the soil index properties under C3 conditions reflect a more stable and less plastic soil compared to the initial soil.

**Table 2.** Index Properties Test

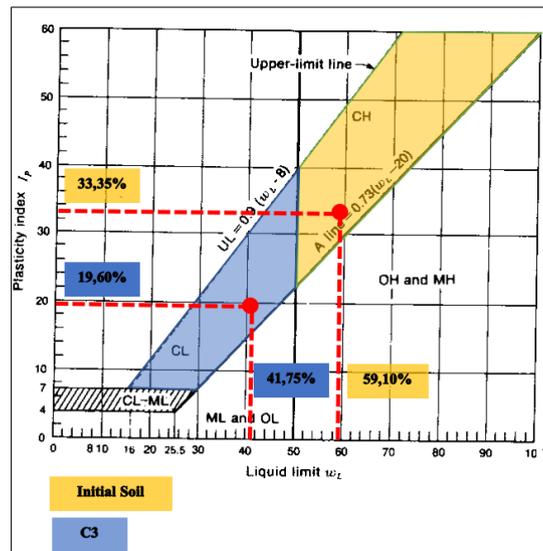
No	Detail	Symbol	Unit	Initial Soil	C3
1	Specific gravity	Gs	-	2,68	2,82
2	Plastic Limit	PL	%	25,75	22,19
3	Liquid Limit	LL	%	59,10	41,79
4	Plasticity Index	PI	%	33,35	19,60

Source: Prepared by the authors.

#### 3.2. Soil Classification

Based on the results of testing the properties and classification according to the Unified Soil Classification System (USCS), the soil tested was classified as fine-grained soil because the percentage passing the No. 200 sieve was 63% (>50%). Under original soil conditions, the Liquid Limit (LL) value was 59.10% and the Plasticity Index (PI) was 33.35%. The PI value was greater than the A-line limit, which is  $0.73(LL - 20) = 28.54\%$ , and the LL value was greater than 50%, so the original soil was classified as CH (inorganic clay with high plasticity or fat clay). Meanwhile, the stabilized soil (Mixture 3) had an LL value of 41.79% and a PI value of 19.60%. This PI value is still above the A-line limit of 15.91%, but with an LL value of less than 50%, the stabilized soil is classified as CL (inorganic clay with low plasticity or lean clay).

The change in soil classification from CH to CL indicates that the stabilization process in Mixture 3 effectively reduces soil plasticity, as evidenced by a significant decrease in LL and PI values. This reduction in plasticity has a positive impact on soil engineering properties, particularly in improving subgrade stability and quality. CH soil is generally soft, highly plastic, and highly sensitive to changes in moisture content, so it tends to lose strength when wet. After stabilization, the soil properties become stiffer, less sticky, and more stable against the effects of water, which is generally indicated by an increase in bearing capacity and soil performance as a construction base layer.



Source: Prepared by the authors.

**Figure 4.** USCS Classification

**Table 3.** USCS Classification

Passed No.	LL > 50%	PI > 0,73 (LL - 20)%	Symbol	Desc.
200		Yes	CH	<i>Fat Clay</i>
>50%	Yes	No	MH	<i>Elastic Silt</i>
		Yes	CL	<i>Lean Clay</i>
	No	No	ML	<i>Lean Silt</i>

Source: Prepared by the authors.

AASHTO classification parameters are determined from the results of Atterberg tests (LL and PI) and particle size distribution (passing No. 200 sieve). Since the percentage passing No. 200 = 63% (>35%), the sample is classified as silt-clay. With LL = 59.1% and PI = 33.35%, the sample does not meet the PI limit for A4/A5 (max 10%) and LL for A4–A6 (max ~40–41%), so it falls into group A7. Criteria A7-5:  $PI \leq LL - 30$ , A7-6:  $PI > LL - 30$ ; because  $33.35 > 59.1 - 30$  (29.1), the final classification is A7-6, which is a soil type dominated by clay and has a value as a base material that is fair to poor.

**Table 4.** AASHTO Classification

General classification	Silt-clay materials			
	A-4	A-5	A-6	A-7
Group classification	A-4	A-5	A-6	A-7-5 / A-7-6
Sieve analysis (% passing)				
2 mm	-	-	-	-
420 μm	-	-	-	-
75 μm	>36	>36	>36	>36
Characteristics (<420 μm)				
Liquid limit	<40	>41	<40	>41
Plasticity index	<10	<10	>11	>11
Usual significant materials	Silty soils		Clayey soils	
General rating as subgrade	Fair to poor			

Source: Prepared by the authors.

### 3.3. Compaction Test

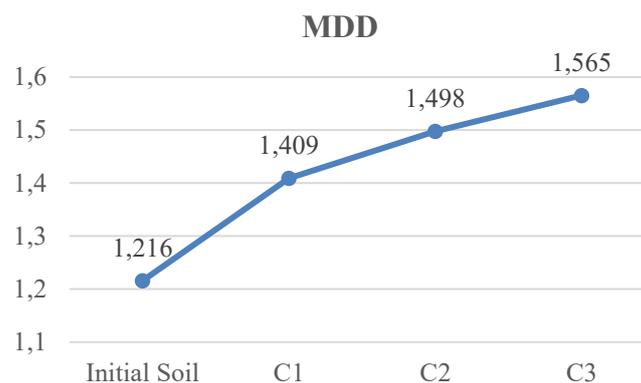
Table 3 shows the compaction test results, including Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) in the initial soil and three treatment variations (C1, C2, and C3). The MDD value of the initial soil only reached 1.216 g/cm<sup>3</sup>, whereas after treatment, there was a gradual increase, namely 1.409 g/cm<sup>3</sup> in C1, 1.498 g/cm<sup>3</sup> in C2, and the highest value of 1.565 g/cm<sup>3</sup> in C3. This increase in MDD indicates that the soil became denser after treatment, allowing the soil particles to be arranged more tightly and producing a higher maximum density.

Conversely, the OMC value showed a downward trend from 37.14% at the initial condition to 30.78% in C1, 27.92% in C2, and 24.55% in C3. This decrease indicates that treated soil requires less water to achieve optimum compaction. This can be attributed to changes in texture and interactions between soil particles, which become more stable, so that they do not require large amounts of water to achieve maximum density. Overall, the combination of increased MDD and decreased OMC indicates that the treatment given is able to improve soil compaction quality, which has the potential to increase its bearing capacity and stability in geotechnical engineering applications.

**Table 5.** Compaction Test

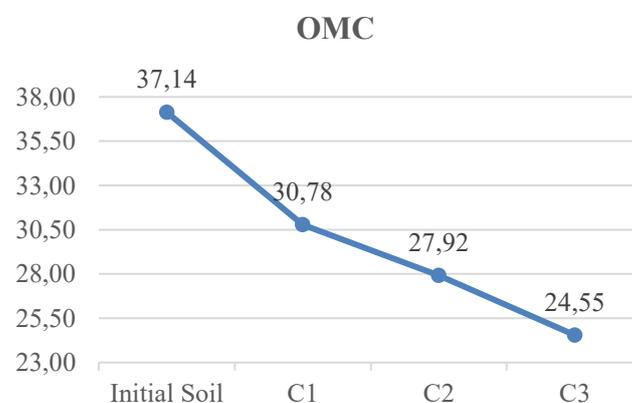
Detail	Unit	Initial Soil	C1	C2	C3
MDD	gr/cm <sup>3</sup>	1,216	1,409	1,498	1,565
OMC	%	37,14	30,78	27,92	24,55

Source: Prepared by the authors.



Source: Prepared by the authors.

**Figure 5.** MDD Test Result



Source: Prepared by the authors.

**Figure 6.** OMC Test Result

### 3.4. Unconfined Compression Strength Test (UCS)

The UCS data in Table 4 shows a consistent and meaningful pattern between conditions C1–C3 and curing time. On day 0, the  $q_u$  values for C1, C2, and C3 were 0.843, 1.666, and 2.733 kg/cm<sup>2</sup>, respectively, and on day 14, they increased to 1.570, 2.763, and 3.655 kg/cm<sup>2</sup>. In absolute terms, the increase in  $q_u$  from 0 to 14 days was +0.727 kg/cm<sup>2</sup> for C1, +1.097 kg/cm<sup>2</sup> for C2, and +0.922 kg/cm<sup>2</sup> for C3. The increase from 0 to 14 days was 86.24% for C1, 65.85% for C2, and 33.74% for C3. Thus, C3 maintained the highest  $q_u$  value throughout the observation period, while C1 showed the largest relative increase, even though its value remained the lowest in absolute terms.

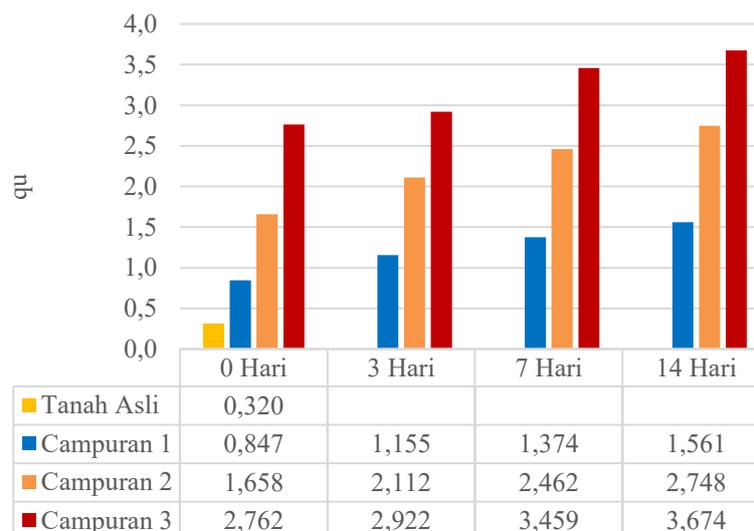
Temporal development analysis also shows differences in the rate of strength increase during the curing interval: for C1, the gradual increase is +0.300 (0 to 3 days), +0.238 (3 to 7 days), and +0.189 kg/cm<sup>2</sup> (7 to 14 days); for C2, they were +0.446, +0.337, and +0.314 kg/cm<sup>2</sup>; for C3, they were +0.174, +0.571, and +0.177 kg/cm<sup>2</sup>. This pattern shows that the rate of increase in  $q_u$  is not linear under some conditions, with a larger jump in the 3 to 7 day range, while under other conditions (C1), the rate of increase decreases gradually over time. This phenomenon is important because it shows that there is an initial phase of rapid strength increase followed by a slower hardening phase.

Mechanistically, the increase in  $q_u$  can be explained by two complementary groups of mechanisms. First, the mechanical-microstructural aspect, namely increased contact between particles and redistribution of stress at the grain interface, increases internal shear resistance, thereby raising the peak unconfined compressive strength. Second, the chemical/physicochemical hardening aspect due to the formation of binding agents or internal reactions such as hydration or pozzolanic reactions. The formation of secondary binding phases or inter-grain hardening increases effective cohesion and adds load capacity.

**Table 6.** UCS Test Result

Curing	Detail	Initial Soil	C1	C2	C3
0 day	$q_u$ (kg/cm <sup>2</sup> )	0,320	0,843	1,666	2,733
3 days	$q_u$ (kg/cm <sup>2</sup> )	-	1,143	2,112	2,907
7 days	$q_u$ (kg/cm <sup>2</sup> )	-	1,381	2,449	3,478
14 days	$q_u$ (kg/cm <sup>2</sup> )	-	1,570	2,763	3,655

Source: Prepared by the authors.



Source: Prepared by the authors.

**Figure 7.** UCS Test Result

The C3 stabilization mixture combination showed the most optimal performance, as it obtained the best results compared to other variations in the entire series of tests, including the Atterberg limits, compaction, and Unconfined Compressive Strength (UCS). However, the maximum combination cannot yet be determined, given that within the range of stabilization material percentages tested, conditions causing a decline in mechanical properties or soil index have not been identified. Thus, increasing the proportion of stabilization material still has the potential to produce higher performance and requires further study.

In a study conducted by Syahril using 12% RHA + 10% phosphoric acid under maximum conditions, a  $q_u$  value of 1.056 kg/cm<sup>2</sup> was obtained from the original soil condition of 0.0386 kg/cm<sup>2</sup> under non-incubation conditions[6]. In the study conducted by the author, it was proven to be more effective in increasing the  $q_u$  value under the same incubation conditions with 12% RHA and RCC-15 13%, increasing the value from the original soil of 0.320 kg/cm<sup>2</sup> to 2.762 kg/cm<sup>2</sup>. In Benny's study using 15% RHA and 10% lime under maximum conditions, a value of 1.983 kg/cm<sup>2</sup> was obtained from the original soil condition of 0.704 kg/cm<sup>2</sup> with a 7 day curing condition[24]. Under the same curing conditions, tests conducted with 12% RHA and 13% RCC-15 stabilizing agents proved to be more effective in increasing the  $q_u$  value of the original soil from 0.320 kg/cm<sup>2</sup> to 3.459 kg/cm<sup>2</sup>.

#### 4. CONCLUSION

Based on the results of the study, the addition of 12% RHA combined with variations of RCC-15 spent catalyst proved effective in improving the characteristics of soft clay soil from Cililin. The initial soil, which was classified as highly plastic clay (CH), showed low compaction and initial strength, requiring improvement. The combination of RHA and RCC-15 resulted in an increase in maximum dry density and a decrease in optimum moisture content, indicating improved soil structure and more efficient water requirements during the compaction process. The most significant improvement was seen in the Unconfined Compressive Strength (UCS) value, where all treatment variations showed strength development over time during curing, with the highest value achieved in treatment C3 (13% RCC-15). These results indicate that pozzolanic reactions and the formation of inter-particle bonds contribute to the increase in soil compressive strength. Overall, the combination of 12% RHA and RCC-15, particularly at doses of 10-13%, offers an economical and environmentally friendly soil stabilisation alternative that is worth considering for subgrade improvement in geotechnical projects. However, for field applications, additional testing related to durability, environmental variations, and microstructure evaluation is required to ensure long-term performance. In addition, this research contributes to the development of environmentally friendly stabilization materials by demonstrating the use of agricultural waste (rice husk ash) and industrial waste (spent catalyst) as active binding agents that provide options with the potential to reduce dependence on conventional cement/lime, as well as opening up avenues for the utilization of waste in soil engineering practices.

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