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Analysis of unconfined compressive and shear strength of clay mixed with a based combination of rice husk ash and NaOH

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ABSTRACT

Clay is a type of soil that is generally characterized by its low load-bearing capacity. Due to the nature of clay minerals, which easily absorb and store water, clay soil is not generally considered suitable for use as a basic building material. This study analyzes changes in the unconfined compressive strength and shear strength of clay soil mixed with rice husk ash (RHA), NaOH, and a combination of rice husk ash and NaOH. The research method involves laboratory tests on original soil samples and soil samples that have been stabilized with varying levels of additives. The results showed that adding rice husk ash, NaOH, or both changed the properties in all tested samples. Unconfined compressive strength testing with varying amounts of rice husk ash (8%, 17%, 25%) showed the highest compressive strength increase of 28.19% at 8% RHA. Meanwhile, adding different amounts of solid NaOH (10%, 14%, and 25%) did not increase the soil's unconfined compressive strength. Mixing rice husk ash and NaOH also did not increase the soil's unconfined compressive strength; rather, it decreased the original soil's rigidity. Direct shear strength tests with RHA variations (8%, 17%, and 25%) showed the greatest increase at 8% of the original soil content, reaching 28.9%. This value decreased with an increased RHA percentage. Adding solid NaOH at different ratios (10%, 14%, and 25%) showed the greatest increase at 10%, with an increase of 14.68%; however, it decreased with increasing NaOH content. The mixture of RHA and NaOH increased in all variations. The highest direct shear strength value occurred in the 25% RHA + 25% NaOH mixture, which increased by 54.13% compared to the original soil. This study showed that RHA can increase soil strength through reactions with water and soil particles. However, these results emphasize the importance of selecting the appropriate types and ratios of stabilizer materials in accordance with engineering requirements.

Keywords: soil stabilization; rice husk ash; NaOH; unconfined compressive strength; shear strength

1 Introduction

Clay soil is a very fine type of soil consisting of particles ranging from microns to submicrons. These particles are formed during the chemical weathering of rocks and their constituent minerals. The minerals found in clay soil are less than 0.002 mm [1]. Clay generally has low bearing capacity, making it unsuitable for use as a base material for construction. This is due to its mineral content, which easily absorbs and retains water, thereby reducing the shear strength of the soil and increasing its potential for compression [2]. Clay soil is really affected by its moisture content. When the soil is wet, it tends to expand, and when it's dry, it shrinks. This change in volume can cause cracks in the foundation of a building. When wet, clay absorbs a lot of water and becomes soft, making it very easy to shape. This condition reduces the soil's ability to withstand external loads, increasing the potential for landslides or mudslides [3]. The high water content of clayey soil can reduce its compressive strength and shear strength. This phenomenon is caused by an increase in the amount of clayey soil, which leads to a reduction in contact between soil particles, thus reducing the strength of the soil. Because of its lower compressive strength, the soil deforms more easily. It doesn't have a lot of shear strength, so it can't take a lot of pressure, especially when it's wet [4]. Therefore, it's important to assess the compressive and shear strength of the soil using special methods to improve its stability and technical characteristics. The goal of soil stabilization is to improve its physical and mechanical properties. The objective includes increasing shear strength and reducing deformation. It also includes stabilizing the volume by controlling the plasticity limit and shrinkage, reducing permeability, and increasing the soil's resistance to aggregate breakdown [5].

Using waste that still has some value can make soil stabilization efforts less expensive. One way they do this is by using something called chemical stabilization, which involves adding natural materials like rice husk ash and chemicals. These chemicals join with the soil's natural compounds to make them more stable. The stabilization technique involves mixing clay soil with rice husk ash, NaOH, and rice husk ash with NaOH. Rice husk ash (RHA) is a by-product of burning rice husks. It's usually considered agricultural waste because it contains a lot of iron oxide and silicate. This material is chemically stable and has physical properties similar to natural sand [6]. Research has shown that RHA contains various chemical compounds, such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, P_2O_5, TiO_2, and MnO [7]. Silicon dioxide (SiO_2) is used as a filler, filling in spaces to make soil more dense. Rice husk ash contains K, Ca, Mg, and Al metal oxides. The metal oxides in rice husk ash have a low standard electrode potential. This finding suggests that these elements are easily oxidized [8].

NaOH is often used not only for rice husking but also as a clay soil stabilizer. Studies have shown that NaOH can be used with water to strengthen clay soils containing montmorillonite minerals [9]. hen clay soil minerals mix with NaOH, they create strong materials (like feldspathoid and hydroxysodalite) that improve the soil's strength [10]. Based on the above information, this study will examine how the addition of rice husk ash, NaOH, or a combination of both affects the technical parameters of clay soil, particularly its unconfined compressive strength and direct shear strength.

Through ion exchange, the ions found in rice husk ash can replace the ions found in the structural minerals of clay soil. For instance, the K and Mg ions in rice husk ash can replace the Na ions in clay soil, which typically leads to soil expansion and softening. This replacement reduces plasticity and increases soil strength.

Stabilizing clay with electrokinetic technology and a lime solution means producing Ca^{2+} ions during the process. These ions are more electronegative than Na^+, K^+, and Mg^+ ions. Consequently, these three ions can break free from their bonds with the clay molecules and be replaced by Ca^{2+} ions. This process is called cation exchange [11].

2 Data dan Methods

2.1 Clay Soil

The clay soil used in the study came from Adian Koting in North Tapanuli Regency, North Sumatra Province, Indonesia. The researcher took two soil samples, undisturbed and disturbed, to do the initial evaluation of the natural soil. The entire research process was carried out in accordance with ASTM (American Society for Testing and Materials) standard procedures. The laboratory test results for the soil samples are presented in **Table 1.**

Table 1. Results of the examination of the characteristics of the original soil

Types of testing	Units	Disturbed Sample	Undisturbed Sample
Moisture Content (w)	%	41.46	44.68
Hydrometer	%	60.6	63.0
Specific Gravity (G_s)		2.638	2.642
Atterberg Limits			
Liquid Limits (L_L)	%	51.52	54.21
Plastic Limits (P_L)	%	34.73	36.31
Plasticity Index (PI)	%	16.79	17.90
Shrinkage Limits (S_L)	%	15.44	16.37
Standard Proctor			
Dry Density (ρd)	gr/cm³	1.526	-
Optimum Moisture Content	%	24.5	-

Therefore, based on the test results in **Table 1**, the soil can be classified according to the Unified Soil Classification System (USCS). The percentage of particles passing through a No. 200 sieve in disturbed soil is 60.6% and in undisturbed soil is 63.0%. The liquid limit (LL) values are 51.52% for disturbed soil and 54.21% for undisturbed soil. Meanwhile, the plasticity index (PI) values are 16.79% for disturbed soil and 17.90% for undisturbed soil. The specific gravity (Gs) of disturbed soil is 2.638 and undisturbed soil is 2.642. Based on the Plasticity Chart, the liquid limit and plasticity index values indicate that the soil type belongs to the MH and OH groups. However, considering the liquid limit values, which are classified as moderate to high, and the specific gravity values in the range of 2.638–2.642, the soil is more likely to be classified as OH (organic clays of medium to high plasticity), which is organic clay with moderate to high plasticity. Therefore, both disturbed and undisturbed soils from the landslide site fall under the OH classification based on the laboratory test results conducted.

2.2 Rice Husk Ash (RHA)

Rice husk ash (RHA) is what is left over when rice husks are burned. Therefore, in theory, it is just waste from the incineration of agricultural products, which is considered basically useless. Rice husk ash contains silica and a pozzolan substance, as it contains free lime, which can harden on its own, as well as aluminum oxide elements, which react easily. [12]. The silicon dioxide and metal oxide content of RHA helps stabilize soil by filling in soil voids, strengthening the bonds between soil particles, and improving the mechanical properties of clayey soils [13], [14] .

Table 2 presents data on the chemical composition of rice husk ash (RHA) obtained from various references. The selection of references was based on their relevance to the research context, particularly in relation to the high silica (SiO_2) content, as well as similarities in combustion methods and material characterization. The three sources were selected because they represent variations in RHA characteristics resulting from different locations and combustion conditions, thereby providing a more comprehensive overview of the main components such as SiO_2, Al_2O_3, CaO, MgO, and Fe_2O_3. These metallic oxides play a significant role in pozzolanic properties and support their potential as additives in soil stabilization in this study.

Table 2. Elements contained in rice husk ash (RHA)

Ref.	Chemical Composition (weight, %)					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O
[15]	82.26	2.56	1.74	2.16	1.74	3.70
[16]	87.22	0.70	1.68	2.12	1.18	1.12
[17]	91.86	0.61	0.58	1.03	0.67	1.91

2.3 Definition and Characteristics of NaOH

Sodium hydroxide (NaOH), also called caustic soda, is an inorganic compound made of Na^+ sodium cations and OH- hydroxide anions. Sodium hydroxide is really soluble in water, and so it absorbs moisture from the air. When you dissolve NaOH in water, you create a strong alkaline solution that releases heat and can cause burns [18]. When NaOH meets silicon dioxide that's dissolved in water, you create sodium silicate. Here's how it goes:

$$SiO_2(s) + 2NaOH(aq) \rightarrow Na_2SiO_3(s) + H_2O(l)$$

Sodium silicate is a widely used compound in industry, for example in the manufacture of soaps and detergents, in cement and concrete raw materials, in adhesives and in absorbent materials. Given its wide range of benefits, this study was conducted to synthesise sodium silicate by melting silicon dioxide with sodium hydroxide (NaOH) [19].

2.4 Testing Method

This study used stabilization materials in the form of rice husk ash (RHA), sodium hydroxide (NaOH), and a mixture of RHA and NaOH. In the initial stage, tests were conducted on the original soil to determine its physical characteristics, such as moisture content, particle size distribution, Atterberg limits (liquid limit, plastic limit, and shrinkage limit), specific gravity, and density. To analyze the changes in microstructure due to the addition of stabilizing agents, observations were made using a Scanning Electron Microscope (SEM) on three samples: original soil, soil mixed with RHA, and soil mixed with NaOH.

Additionally, to monitor changes in the physical properties of the soil, property index tests were conducted on soil samples mixed with stabilizers. These tests included moisture content tests, specific gravity tests, and Atterberg limits. The main tests in this study were unconfined compressive strength (UCS) and direct shear strength (DS), aimed at evaluating changes in the mechanical properties of the soil after mixing with stabilizer materials, namely rice husk ash, NaOH, and rice husk ash plus NaOH.

RHA (Rice Husk ASH) was used as a stabilizer material without specific control of the combustion temperature. The ash was obtained from the open-air combustion of rice husks by local communities, without the use of a furnace or specific temperature control. Several studies indicate that ash from uncontrolled combustion still contains a significant amount of amorphous silica, which can contribute to pozzolanic reactions when mixed with soil. The RHA was sieved using a No. 40 sieve (< 0.425 mm) to ensure particle homogeneity and fineness before being mixed into the soil.

NaOH (Sodium Hydroxide) is used in pellet form with 99% purity and is then ground to ensure that the particle size of NaOH matches the particle size of the soil, resulting in uniform fineness during mixing (homogeneous).

The stabilization combinations tested include:

- Original soil without stabilizer
- Soil with RHA: 8%, 17%, and 25%
- Soil with NaOH: 10%, 14%, and 25%
- Soil with RHA + NaOH combinations: 8% RHA + 10% NaOH, 10% RHA + 8% NaOH, and 25% RHA + 25% NaOH

To ensure consistency and comparability between samples, each mixing was performed using 3000 grams of soil. The addition of stabilizer materials was calculated based on the dry weight of the soil, allowing the proportion of each percentage of the mixture to be precisely controlled for each designed variation. After the mixing process, all samples were prepared and cured for 7 days to allow sufficient time for pozzolanic reactions or cementation processes to occur before further testing.

2.5 Laboratory Testing

2.5.1 Scanning Electron Microscope (SEM)

A scanning electron microscope, or SEM, is an electron microscope that uses a focused beam of electrons to create an image of a sample by scanning it at a certain magnification level. Most SEMs have a spot size of less than 10 nm, and electrons are collected from the lens (up to a depth of 1 μm) to create a signal that's used to generate the image [20]. Scanning electron microscopy, or SEM, is used to examine the surface of the sample. In stable soil, SEM can show changes in the structure of the particles, the distribution of the pores, and the presence of bonds between the soil and the materials that stabilise it [21].

Microstructural morphology testing was conducted on two types of samples, namely native soil and soil that had been stabilized by adding 25% rice husk ash (RHA) and 25% NaOH, respectively. All samples observed were prepared in the form of dry powder to ensure clarity of the microstructure without the influence of moisture.

2.5.2 Index Properties

To figure out the soil's characteristics, you've got to run a test for soil properties [22]. Soil property indices are basic soil properties that are used to identify soil types and conditions, and they correlate with mechanical properties [23]. The researcher figure out these properties with lab tests, and that includes things like water content, specific gravity, and how big the particles are. The researcher also look at Atterberg limits—that's the liquid limit, plasticity limit, plasticity index, and shrinkage limit. And The researcher run other tests too, like hydrometer analysis and linear shrinkage tests.

Soil index testing includes moisture content, particle size analysis, Atterberg limits (liquid limit and plastic limit), and specific gravity. All tests were conducted on soil samples that passed a No. 40 sieve (0.425 mm), except for particle size analysis.

- Moisture content was tested on native clay soil and soil mixtures with varying rice husk ash content (8%, 17%, and 25%), variations in NaOH (10%, 14%, and 25%), and combinations of both (8% RHA + 10% NaOH, 10% RHA + 8% NaOH, and 25% RHA + 25% NaOH), in accordance with ASTM D2216.
- Particle size analysis was performed only on native clay soil using the hydrometer method based on ASTM D422.
- The liquid limit and plastic limit were tested on native soil and all mixture variations using the Casagrande apparatus in accordance with ASTM D4318.
- Specific gravity was determined on native soil and all mixture variations based on the procedure in ASTM D854.

2.5.3 Standard Proctor Compaction Test

Standard compaction tests were performed on soil samples that passed a No. 4 sieve (4.75 mm) on native soil in accordance with ASTM D698. The specimens were 101 mm in diameter and 117.5 mm in height. The degree of soil compaction affects several technical properties, such as unconfined compressive strength and direct shear strength. Therefore, it is important to achieve the desired relative compaction level to meet the required soil characteristics.

2.5.4 Unconfined Compressive Strength

Unconfined Compression Strength is one of the most common soil mechanics tests used on cohesive soils, like clay soils. The point of the test is to see how well the soil can handle being squished until it caves in or reaches 20% deformation. The test provides you a general idea of how soil deforms under pressure [24]. The test results provide us info on the parameters of collapse stress (qu), cohesion (cu), and soil shear stress. The free fluctuating compressive strength value, or q_m, is determined by comparing the readings from the stress gauge, or P, and the cross-sectional area, or A, of the test object. These are expressed in kN/m^2 [25].

This test was conducted on soil samples that had passed through a No. 4 sieve (4.75 mm), consisting of native clay soil, soil mixed with rice husk ash (8%, 17%, and 25%), soil mixed with NaOH (10%, 14%, and 25%), as well as mixtures of rice husk ash and NaOH (8% RHA + 10% NaOH, 10% RHA + 8% NaOH, and 25% RHA + 25% NaOH). All tests were conducted in accordance with ASTM D2166 standards, under conditions of optimum moisture content (OMC) and maximum dry unit weight after compaction.

2.5.5 Direct Shear Strength

Soil shear strength, as Hardiyatmo says in his book, is the force that soil particles put up against pressure or tension. The strength of soil depends on the forces between its particles. Direct shear testing is intended to determine the cohesion (c) and internal friction angle (φ) of soil by applying a shear load directly [26]. Soil cohesion is all about the forces that attract particles to each other. Soil shear strength is determined by a couple of things, like the internal friction angle and cohesion. These are the things that determine how much the soil can be deformed when it's under stress [27]. Shear strength is used to figure out the shear characteristics for different combinations of clay soil mixtures with stabilisers [28].

This test was conducted on soil samples that had passed through a No. 4 sieve (4.75 mm), including native clay soil and soil mixed with various additives, namely rice husk ash (8%, 17%, and 25%), NaOH (10%, 14%, and 25%), and combinations of rice husk ash and NaOH (8% RHA + 10% NaOH, 10% RHA + 8% NaOH, and 25% RHA + 25% NaOH). All tests were conducted according to ASTM D3080 standards, under optimal moisture content (OMC) conditions and maximum dry unit weight from compaction tests.

3 Results and Discussion

3.1 Scanning Electron Microscope (SEM) Microstructure

SEM photo analysis was performed at 3000x magnification on the original soil and on the mixture with the highest percentage of RHA and NaOH content (25% RHA and 25% NaOH). The results of the SEM test characterisation of the sample are shown in Figures 1, 2, and 3.

Based on **Figure 1**, the SEM image of the original soil shows that the particle texture appears uneven and coarse, with fine particles mixed with larger particles. The particles appear to stick together, indicating that this soil has plasticity. Small, uneven pores are scattered among the particles. The microscopic structure is dense and compact, indicating that the soil has a high water retention capacity. The grain shape is irregular, with a rough surface. There are indications of flat clay particles colliding and sticking together, which is a characteristic of clay minerals such as kaolinite, montmorillonite, or illite. This property makes the soil highly cohesive and difficult for water to pass through.

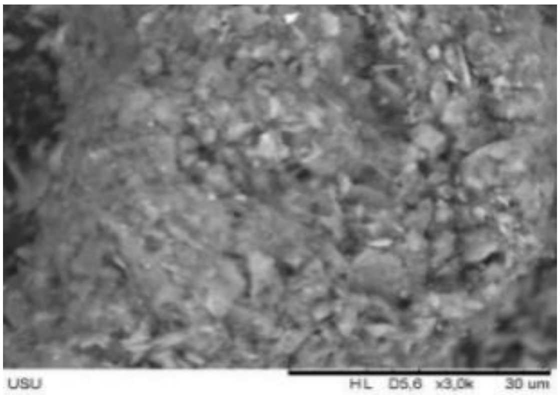

Figure 1. Results of SEM photo testing on original soil

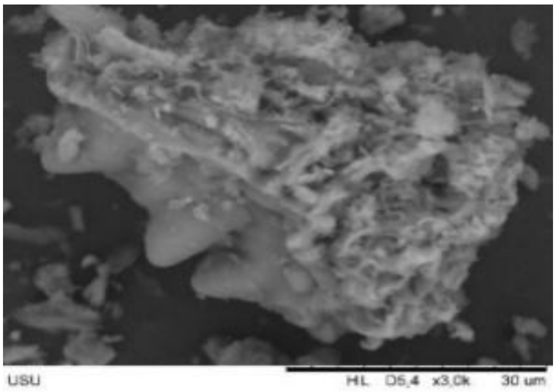

Figure 2. Results of SEM photo testing on soil mixed with 25% RHA

Based on **Figure 2**, the SEM image of soil mixed with 25% RHA shows that the particle morphology is irregular and coarse-textured, with some particles resembling plates or flakes. Most particles appear to be interconnected and form aggregates, indicating the formation of interparticle bonds as a result of RHA addition. The fibrous surface observed is a characteristic feature of the amorphous silica residue in RHA. This amorphous silica has the ability to absorb water and fill soil pores, thereby forming a more compact soil microstructure. Additionally, the pozzolanic reaction that occurs forms binding compounds (cementation) that can reduce soil plasticity, as evidenced by the decrease in Atterberg limit values. However, it is important to note the percentage of RHA mixed into the soil; if too much RHA is added, weaker bonds form, making the soil brittle.

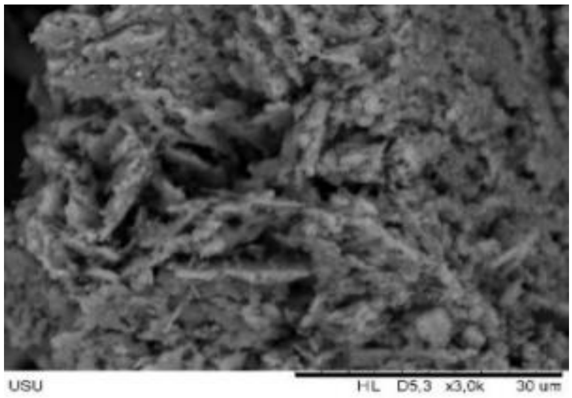

Figure 3. Results of SEM photo testing on soil mixed with 25% NaOH

Based on **Figure 3**, the results of Scanning Electron Microscope (SEM) images of soil mixed with 25% NaOH show that the microscopic structure of the soil has changed. The particle texture becomes denser and coarser with a fibrous surface. The particle morphology shows layering and partial rounding, as well as the formation of structures resembling flat plates or irregularly shaped fragments that are stacked and bound together. This indicates that NaOH triggers changes in particle shape through the softening of the crystalline structure of clay minerals, accompanied by dispersion and recombination phenomena. These changes align with the results of Atterberg limit testing, where the plasticity index increases with increasing NaOH content, indicating enhanced clay mineral activity due to the chemical interactions occurring.

3.2 Index Properties

3.2.1 Soil Property Index with RHA mixture

Several tests were conducted to determine the effect of adding RHA on the property index. The results are shown in **Table 3**, which shows the changes in the physical properties of the soil as the percentage of RHA increases.

Table 3. Soil property index with RHA mixture

Type of Tests	Units	Variasi RHA		
		8%	17%	25%
Moisture Content (w)	%	21.95	19.05	17.42
Specific Gravity (G_s)		2.647	2.661	2.673
Liquid Limits (L_L)	%	47.79	43.36	40.48
Plastic Limits (P_L)	%	35.36	36.15	36.67
Plasticity Index (PI)	%	12.43	7.21	3.81
Shrinkage Limits (S_L)	%	18.64	20.54	23.89

When RHA is added to clay, it has a significant impact on the physical properties of the soil. The silicon dioxide in RHA reduces the water content, liquid limit, and plasticity index and increases the shrinkage limit and specific gravity. This happens because silicon dioxide works like a pozzolanic material, so it soaks up water and fills the spaces between soil particles. This process makes the soil denser, which changes its structure and texture, making it more granular and less cohesive.

3.2.2 Soil Property Index with NaOH Mixture

Several tests were conducted to determine the effect of NaOH addition on property indices. The results of these tests are shown in **Table 4**, which shows changes in soil physical properties with increasing RHA percentage levels.

Table 4. Soil property index with NaOH mixture

Type of Tests	Units	Variations of NaOH		
		10%	14%	25%
Moisture Content (w)	%	24.22	23.97	22.70
Specific Gravity (G_s)		2,648	2.641	2.627
Liquid Limits (L_L)	%	53.55	56.99	61.96
Plastic Limits (P_L)	%	35.22	35.06	33.52
Plasticity Index (PI)	%	18.32	21.93	28.44
Shrinkage Limits (S_L)	%	16.87	17.65	19.21

When NaOH is added to clay, the water content decreases due to a chemical reaction with the soil minerals, resulting in reduced porosity. But NaOH also increases the liquidity limit, plasticity index, and shrinkage limit, especially at high concentrations, because of its hygroscopic nature and soil dispersion potential. The specific gravity goes up at an NaOH concentration of 10% but goes down at higher levels because there are too many OH- ions. That makes it difficult for stable geopolymer structures to form.

3.2.3 Soil property index with RHA and NaOH mixture

The following table shows a number of tests to see how the addition of RHA and NaOH affects soil properties. The results can be seen in **Table 5**, which shows increasingly significant changes and differences in soil physical properties.

Table 5. Soil property index with RHA mixed and NaOH mixture

Type of Tests	Units	Variations of RHA + NaOH		
		8% RHA + 10% NaOH	10% RHA + 8% NaOH	25% RHA + 25% NaOH
Moisture Content (w)	%	21,21	19,05	14,94
Specific Gravity (G_s)		2.658	2,664	2,676
Liquid Limits (L_L)	%	48,58	45,87	40,50
Plastic Limits (P_L)	%	34,27	33,52	29,84
Plasticity Index (PI)	%	14,31	12,35	10,66
Shrinkage Limits (S_L)	%	17,42	18,18	21,26

Mixing RHA and NaOH simultaneously in clay causes a decrease in water content, liquidity limit, and plasticity index of the soil, but there is an increase in shrinkage limit and specific gravity. This effect is due to the formation of C-S-H and sodium silicate (Na_2SiO_3) compounds. These compounds are produced during the reaction between the silicon dioxide in RHA and NaOH. They bind water and strengthen the soil structure. This process makes the soil less plastic and more dense.

3.3 Unconfined Compressive Strength

3.3.1 Unconfined Compressive Strength of Soil with RHA Mixture

Unconfined compression tests were conducted to determine the effect of mixtures containing rice husk ash on the compressive strength of clay. The results of these tests are shown in **Table 6**.

Table 6. Results of unconfined compressive strength (qu) and cohesion (Cu) tests with RHA mixture

Variation of mixture	Unconfined Compressive Strength (qu) (kPa)	Cohesion (cu) (kPa)
0% RHA	7.14	3.57
8% RHA	9.15	4.58
17% RHA	7.74	3.87
25% RHA	6.09	3.04

Table 6 shows that adding RHA to clay affects its unconfined compressive strength (UCS). The UCS showed the greatest increase at 8% content, with an increase of up to 28.19%. The cohesion value increased by up to 28.17% compared to the original soil value. But as the percentage of RHA went up, the unconfined compressive strength went down. This decrease in UCS could be because adding too much RHA to the soil makes a weak bond between the soil and the cementitious compound.

3.3.2 Unconfined compressive strength of soil with NaOH mixture

Some unconfined compressive strength tests were conducted to see what would happen to the clay's compressive strength when we added a NaOH mixture. Test results can be seen in **Table 7**.

Table 7. Results of compressive strength (qu) and cohesion (cu) tests with NaOH mixture

Variations of Mixture	Unconfined Compressive Strength (qu) (kPa)	Cohesion (cu) (kPa)
0% NaOH	7.14	3.57
10% NaOH	5.54	2.77
14% NaOH	4.24	2,12
25% NaOH	3.35	1.68

Table 7 shows how adding NaOH changes the unconfined compressive strength (UCS) of clay. The UCS and cohesion (Cu) values go down when 10%, 14%, and 25% NaOH are added. This happens because of the reaction between NaOH and water, which makes the polarity of the Na^+ ion in NaOH. This attracts water molecules to come closer to the ion.

The increase in the number of Na^+ ions in the soil causes soil dispersion, so the clay particles lose their cohesion.

3.3.3 Unconfined Compressive Strength of Soil with mixture of RHA and NaOH

Unconfined compressive strength (qu) and cohesive strength (cu) tests were performed to evaluate the effect of the addition of RHA + NaOH on the open compressive strength of clayey soils. The results of the tests are shown in **Table 8.**

Table 8. Results of unconfined compressive strength (qu) and cohesion (cu) tests with a mixture of RHA and NaOH

Variation of mixture	Unconfined Compressive Strength (qu) (kPa)	Cohesion cu (kPa)
0%	7.14	3.57
8% RHA + 10% NaOH	4.29	2.15
10% RHA + 8% NaOH	4.59	2.30
25% RHA + 25% NaOH	0.54	0.27

Table 8 shows that adding RHA and NaOH changes the strength of the original soil (disturbed soil). The strength (qu) and cohesion (cu) values of the original soil decrease with each change. Adding more NaOH doesn't really make a big difference in soil strength. If the soil has too much alkali, it can become brittle and more likely to be damaged.

3.4 Direct Shear Strength

3.4.1 Direct Shear Strength of Soil with RHA Mixture

Shear strength tests were conducted to determine the effect of adding RHA to the soil on soil cohesion (c) and shear strength (τ). The results of tests with various RHA mixtures are shown in **Table 9.**

Table 9. Results of direct shear strength test with RHA mixture

Variations of Mixture	Cohesion (c) (kPa)	Shear Strength (τ) (kPa)
0% RHA	0.41	4.36
8% RHA	0.64	5.62
17% RHA	0.45	5.10
25% RHA	0.38	4.71

According to Table 9, the shear strength of the soil mixed with RHA changed. The highest shear strength was seen in the soil mixed with 8% RHA, which increased the shear strength (τ) by up to 28.90%. But as the percentage of RHA went up, the shear strength went down. This might be because the extra RHA in the soil didn't form a strong enough bond with the cement mixture, which made it hard to stick together.

3.4.2 Direct Shear Strength of Soil with NaOH Mixture

A shear strength test was carried out to determine the influence of soil NaOH shear strength parameters, namely cohesion (c) and shear modulus (τ). The results of the shear strength test with variation of NaOH system content are shown in **Table 10.**

Table 10. Results of direct shear strength test with NaOH mixture

Variations of Mixture	Cohesion (c) (kPa)	Shear Strength (τ) (kPa
0% NaOH	0.41	4.36
10% NaOH	4.53	5.00
14% NaOH	4.28	4.63
25% NaOH	3.81	4.06

The test results in **Table 10** indicate that when 10% NaOH was added, the soil's shear strength increased by up to 14.67% compared to the original soil. With NaOH dosage exceeding 10%, the shear strength of the soil decreased. This shows that NaOH is hygroscopic, namely its ability to absorb and bind water around itself—in this case, soil molecules. The excess water reduces the internal friction and makes the soil softer and more susceptible to deformation under load, thus reducing the shear strength.

3.4.3 Direct Shear Strength Soil with RHA and NaOH Mixture

A Shear strength tests were conducted to determine the effect of soil shear strength parameters mixed with RHA and NaOH, namely cohesion (c) and shear modulus (τ). The results of the shear strength tests with variations in the RHA and NaOH system content are shown in **Table 11.**

Table 11. Results of direct shear strength test with RHA and NaOH mixture

Variations of Mixture	Cohesion (c) (kPa)	Shear Strength (τ)
0%	0.41	4.36
8% RHA + 10% NaOH	3.62	5.04
10% RHA + 8% NaOH	2.14	5.13
25% RHA + 25% NaOH	3.85	6.72

Based on **Table 11**, it was found that the shear strength of the soil mixed with RHA and NaOH increased with all variations. The highest shear strength was observed in soils mixed with 25% RHA + 25% NaOH, where shear strength (τ) increased by 54.13% compared to the shear strength of the original soil. This increase is due to the fact that NaOH reacts as an activator with SiO_2 in RHA. The gel-like substance produced by this reaction fills the pores of the soil mass and strengthens the closing force created by the coupling between the soil particles. The reaction between RHA increases the frictional force of the soil, limits the sliding of particles in the soil, and strengthens the tensile effect of the fibers. The tensile effect created by the fibers restricts the movement of soil particles, thereby limiting the deformation of the soil under normal and horizontal loads.

4 Conclusion

The results of a study conducted with RHA and NaOH (mixed separately or together) on clayey soils at Tarutung-Sibolga Highway, Pagaran Lambung I village, Adian Koting district, North Tapanuli, led to the following conclusions:

a. RHA has several effects on clay: RHA reduces water content (10.3–28.84)%, melting point (7.24–21.43)%, and plasticity index (25.97–77.31)%, but increases the shrinkage point (20.73–54.73)% and specific gravity (0.34–1.33)%. When using NaOH, there is an increase in water content (1.06–7.27)%, melting point (7.24–21.43)%, plasticity index (9.11–69.34)%, and shrinkage point (9.26–24.42)%. The specific gravity increased at a NaOH content of 10% and decreased at higher percentages. The results of the soil property index tests indicate that using the same amount of RHA (50:50) with NaOH yields better results than using a higher amount of NaOH in the mixture. When soil properties are mixed with RHA and NaOH simultaneously, the results are similar to those of soil mixed with RHA alone, but with higher values of change (increase or decrease).

b. The unconfined compressive strength and direct shear strength of RHA-mixed soil increased by 28.19% when 8% RHA was added. However, for higher mixing percentages, the values decreased. The highest shear strength (τ) was also obtained in the 8% mixture of rice husk ash, representing an increase of 28.19% compared to the shear strength of soil without the addition of a stabilizer. The test results showed that the unconfined compressive strength (qu) decreased with increasing NaOH content. It was found that the highest shear strength (τ) was achieved with a 10% NaOH mixture, which was 14.68% higher than the shear strength of the original soil. However, this strength decreased at higher NaOH mixture percentages. Several experiments with RHA and NaOH mixtures showed that adding increasing amounts of NaOH to RHA did not significantly affect the unconfined compressive strength (qu) of the soil. In fact, it seems that the strength decreases with each variation. Therefore, based on these results, it can be concluded that using large amounts of NaOH does not actually make the soil stronger. However, when it comes to the shear strength of the soil (τ), mixing NaOH with clay can actually increase the strength at different mixture ratios. The mixture of 25% RHA and 25% NaOH showed the greatest increase (54.13%) in the initial shear strength of the soil. The strength of soil mixed with RHA and NaOH simultaneously showed a decreasing trend. When using a combination of RHA and NaOH to strengthen clay, caution is needed and sufficient knowledge is required.

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