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Subgrade Optimization with Coconut Shell Ash Addition on Glee Gurah Clay Soil

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ABSTRACT

Improving subgrade bearing capacity is a crucial aspect of highway construction. Clay soils, which have high plasticity and low bearing capacity, often require improvement to increase their stability and strength. This research examines the effect of coconut shell ash addition on the bearing capacity of clay soil in Glee Gurah village. The research aims to identify the impact of coconut shell ash stabilization on the mechanical characteristics of clay soil as a highway subgrade, focusing on soil compaction and CBR values. The research was conducted through a series of laboratory tests which included soil classification according to AASHTO and USCS, as well as compaction (Proctor) and CBR testing. The percentage variations of coconut shell ash used were 0%, 3%, 6%, 9%, and 12%. The results showed that the addition of coconut shell ash increased the bearing capacity of clay soil. The maximum dry volume weight increased from 1.464 gr/cm³ (no mixture) to 1.540 gr/cm³ at the addition of 12% coconut shell ash. The optimum moisture content decreased with increasing ash percentage, from 22.70% to 20.20%. The unsoaked CBR value also increased significantly, from 11.06% (no mixture) to 17.78% at the addition of 12% coconut shell ash, with a total CBR percentage increase of 60.80%. Thus, the use of 12% coconut shell ash > 20% (Good), so that ANOVA shows a p value <0.05, which means that the addition coconut shell ash significantly increases the bearing capacity of clay soil and is effective in strength of subgrades with moderate traffic categories.

Key words: *soil stabilization, clay, Pavement, subgrade, coconut shell ash*

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INTRODUCTION

Soil is a crucial aspect in any construction project, both for building and highway construction. In highway construction, soil functions as a subgrade that supports the pavement structure above it. The quality of the soil used as a subgrade greatly affects the life of the pavement (Budiman, 2013).

The soil used as the base layer of a building, also known as the subgrade, must have sufficient bearing capacity to withstand structural loads. Good subgrade strength is also important to prevent the pavement structure from being damaged by traffic loads (Setiawan, 2021). However, not all soils are suitable for use as subgrades. Many soils have unsuitable conditions, such as low bearing capacity, high compressibility, and sensitivity to changes in moisture content. These soils are often considered problematic and require improvement to achieve the required quality and strength.

Soil stabilization can be done in two ways, namely mechanical stabilization which is done by compacting the soil using mechanical equipment (Amran & Permadi, 2021; Chayati & Taqwa, 2021), Chemical stabilization, on the other hand, is done using mixing materials, which is done by mixing soil with stabilizing materials such as cement, lime, fly ash, or other materials (Zulnasari et al., 2021). The choice of stabilization material used in a place depends on the type of soil and the amount of stabilization material available (Zulnasari et al., 2021; Insan et al. 2020).

The use of materials with coconut shell ash substitution as a clay stabilization material. Coconut shell ash is often known as the end result of the combustion process of coconut shell or charcoal. The clay soil obtained is clay soil located in Glee Gurah Village, Peukan Bada District, Aceh Besar Regency. At this location is a place of access for residents to do their daily activities that will be built pavement. The use of charcoal waste as a mixture of soil additions to increase stabilization that can reduce cracks in the pavement is considered to increase the CBR value of the soil, because the ash is able to bind carbon and can reduce shrinkage expansion in the soil so that the soil plasticity index can be reduced (Arbi, 2018). Variation of stabilization material mixture used in this study were 3%, 6%, 9% and 12%.

Based on the background and problem identification above, the following problems can be formulated;

1. What is the original soil CBR value obtained from the test?

2. What is the effect of coconut shell ash stabilization on clay soil with 3%, 6%, 9% and 12% levels on soil mechanical properties?
3. What is the optimum percentage of coconut shell ash stabilization on clay soil to obtain subgrade CBR value?

This research can be used as one of the literatures for further research on improving soil properties with coconut shell ash. It is one of the factors considered when choosing a method of improving soil properties in the field, especially in highway construction.

The layer that lies between the subgrade and the vehicle wheels is called the pavement (Farida and Hakim, 2021). Its function is to accommodate traffic loads without causing significant damage. Pavement consists of various layers arranged from bottom to top. These include the subgrade layer; the sub-base course; the base course; and the surface or cover layer (Exposto, et al., 2017).

Figure 1: Road Pavement Structure
Source: Pavement Design Manual 2013

Clay is one type of soil that has cohesive and plastic properties. Cohesive properties mean that soil grains stick together, while plastic properties refer to the ability of soil to change shape without experiencing volume changes or rupture (Fahriana, et al 2019).

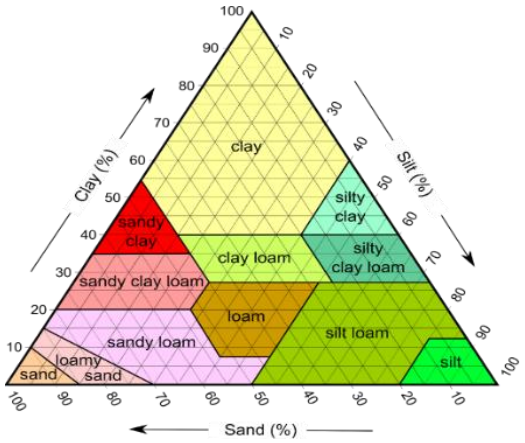

Figure 2: Triangle of soil size fractions
Source: Das, 2019

The comparison between clay, silt, and sand depicted in the texture triangle determines soil texture (Nurul & Budi 2016), which is done by drawing lines showing that soil consists of grains of different sizes and shapes. One of the soil texture classes is clay, which is located in the centre of the texture triangle. parallel to the base of the triangle until the three lines intersect. Determination of soil fraction is expressed as a percentage based on the total dry weight of the soil.

Table 1. Composition of clay soil

Component	Coarse Clay (%)	Fine Clay (%)
SiO_2	48,07	40,61
Al_2O_3	18,83	18,91
CaO	4,98	6,24
K_2O	2,57	2,62

Source: Rahmat, et al (2020)

Soil stabilization is the process of improving the original soil to improve the properties of the soil so that it locks together and is more tightly arranged. Soil stabilization can be done mechanically and chemically (Roshadewi, 2021). For chemical stabilization, additives such as bitumen, cement, fly ash, gypsum, and rice husk ash are added, as shown in the next figure.

Figure 3: Stabilized clay soil with geotextile
Source: Engineering Daily, 2023

Mechanical stabilization can be done by compaction of soil using heavy equipment such as smooth wheel roller, tandem roller, and pneumatic tired roller.

Soil stabilization aims to increase soil strength, reduce volume changes, and decrease soil permeability (Nurussalam, et al 2024). The process of changing soil properties to meet specific engineering requirements with the aim of increasing soil bearing capacity, reducing soil settlement, and decreasing soil permeability and development. Any of the following actions may be included in stabilization:

1. to increase soil density; add inactive materials to increase cohesion and shear strength; and chemically and physically alter the soil;
2. Lowering the water level in the soil through the process of soil drainage; and

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3. Replace unfit soil to be used for construction.

The coconut shell is a hard wood with a moisture content of about 9% - 10% when calculated based on dry weight. This shell is located inside the coconut after the coir and is a hard layer with a thickness of 3 - 5 mm (Halim & Rante 2024). Coconut shell charcoal has so far been widely used for fuel by small and large traders. The use of charcoal in daily life produces ash as the final result of the combustion process. As far as some sources are concerned, coconut shell ash has never been used for soil stabilization. Therefore, it is an alternative in this research to utilize the ash located in Cot Seunong Village, Montasik. The use of coconut shell ash in stabilization efforts here is very beneficial to various sources because this shell is seen as waste and can be obtained from traders in markets or coconut graters.

In the process of utilizing coconut shell ash, this shell must first be burned for + 3 hours (Saputra, et al 2021), until it completely becomes ash and is filtered with a no # 40 filter. After the shell has been burned to ash, the heat is still felt even though it has been stored in a closed container for days.

Figure 4. Coconut Shell Ash before and after combustion
Source: Ministry of Agriculture, 2023

Table 2. Composition of coconut shell ash.

Chemical	Percentage
Silica Dioxide	7,40
Calcium Oxide	1,43
Magnesium Oxide	2,78
Ferum Trioxide	1,74
Aluminum Trioxide (Al2O3)	8,20

Source: Banda Aceh Industrial Research and Standardization Agency (2010)

Atterberg Limits are important parameters in soil mechanics used to classify soils based on their consistency properties (Akbar & Brio 2018). These parameters include Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), Here is a further explanation of each of these parameters.

Plasticity Index (PI) Plasticity Index is useful to determine the amount of clay particles in the soil. Plasticity Index is the difference between Liquid Limit and Plastic Limit (Hangge, et al 2021).

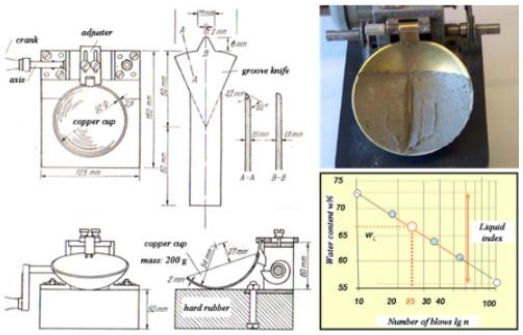

Figure 5. Casagrande
Source: Hardiyatmo, 2006

Table 3. Plasticity Index

PI	Properties	
0	Non Plastic	Sand
<7	Low Plasticity	Silt
7 - 17	Medium Plasticity	Silty clay
>17	High Plasticity	clay

Source: Hardiyatmo, 2006

The process by which air in soil pores is mechanically expelled (raked or pounded) so that soil particles become compacted is known as soil compaction (Ramadhan et al., 2024).

In other words, soil compaction is when the volume of air-filled voids decreases while the solids and water content remain the same. According to Hardiyatmo (2003), there are two purposes of soil compaction. The first is to increase the shear strength of the soil and the second is to reduce the compressibility of the soil, reduce the permeability rate, and reduce the volume changes caused by changes in moisture content.

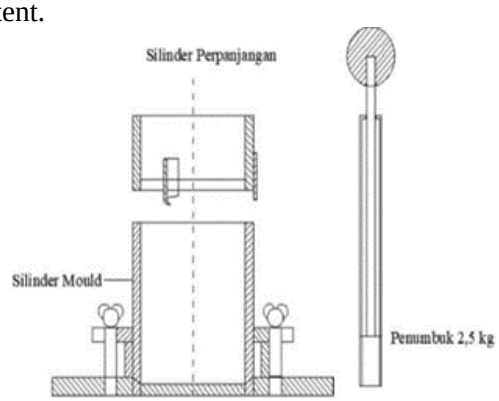

Figure 6. Standard proctor test
Source: Hardiyatmo, 2003

California Bearing Ratio (CBR) is an index used in geotechnical engineering to measure the ability of soil to support loads (Kamaluddin, et al 2022). CBR provides information on the extent to which the soil can maintain its strength and resistance to deformation under load. This index is measured by testing soil samples in the laboratory using a

CBR tester, which involves the penetration of a steel conus into the soil sample.

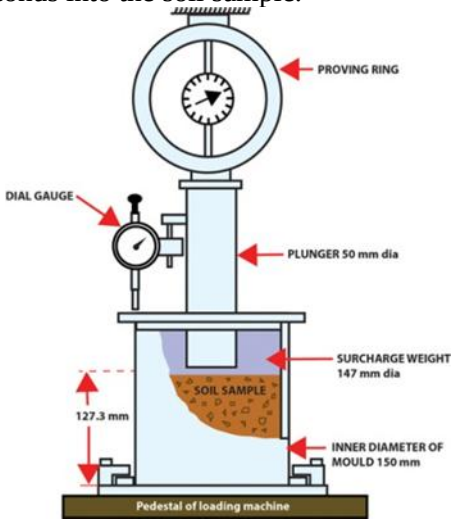

Figure 7. CBR
Source: Hardiyatmo (2006)

The test results are expressed as a percentage of the soil's resistance to penetration compared to the resistance of a standard soil (Khotima, 2022). CBR testing is important in the planning of pavements and airport runways as it provides a comprehensive evaluation of the strength and bearing capacity of the soil. The CBR value is also affected by several factors, such as soil type, moisture content, soil density, organic matter content, soil mineralogy, soil structure, soil lateral pressure, and soil temperature.

Laboratory CBR is measured under two conditions. Unsoaked CBR is lower than soaked CBR under unsubmerged conditions (Fishal, et al., 2018). However, since the soaked condition is a frequent condition in the field, the wet CBR price is used as the basis for building construction calculations. This is because building construction is always affected by water.

Table 4. CBR Subgrade

Rate	*Subgrade*	Description
< 3%	Poor	Compaction required
3%-5%	Normal	The need for compaction depends on the road category
5%-15%	Excelent	Normal compaction is not required except for heavy traffic.

Source: Hardiyatmo (2006)

RESEARCH METHOD

The research was conducted at the Highway Laboratory of the Faculty of Engineering, University of Muhammadiyah Aceh. preparation of test soil, physical testing of soil, and determination of coconut shell ash variants as well as the number of test specimens, mixing and testing methods.

The making of this original object by mixing the original soil, namely organic clay soil with the addition of Lime and water with the percentage of additions in this study of 0%, 3%, 6%, 9% and 12% of the weight of dry soil. The soil was taken using a hoe and put into sacks, so that it was easy to transport. Soil samples before the research is done first removed the moisture content by drying the soil samples in the sun ± 1 week.

Figure 8. Clay soil sample

Table 5. Total test specimens

No	Properties	Totals
1	Liquid limit testing	1
2	Plastic limit testing	1
3	Sieve Testing	1
4	Proctor Testing + Variation of Coconut Shell Ash	5
5	CBR Testing + Variation of Coconut Shell Ash	5

The test specimen preparation process will begin with pounding the soil chunks to pass sieve number 4 (4.76 mm), then adding coconut shell ash with the addition of 0%, 3%, 6%, 9% and 12%. The mixed soil was given water to reach the OMC moisture content obtained by compaction experiments. The calculation results of soil weight and coconut shell ash can be seen in the table below.

Table 6. Variation of soil with coconut shell ash mixture (Proctor)

Percentage (%)	Original Soil (gr)	Coconut shell ash (gr)
0	2000,00	0
3	2000,00	145,78
6	2000,00	300,87
9	2000,00	466,18
12	2000,00	642,76

In this case it is done by testing CBR Unsoaked to assess the bearing capacity of the soil in dry conditions, without the influence of water. With the aim of determining the ability of the soil to withstand loads in the absence of water saturation. This is important for soil stability analysis, especially in areas that tend to be dry or in conditions where water is not available.

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Table 7. Variation of soil and coconut shell ash mixture (Unsoaked CBR)

Persentase (%)	Original Soil (gr)	Coconut shell ash (gr)
0	5000,00	0
3	5000,00	145,78
6	5000,00	300,87
9	5000,00	466,18
12	5000,00	642,76

Preparation The samples to be tested are taken from the relevant locations and prepared by drying to the desired moisture content. The soil samples are then compacted using a compactor in accordance with Proctor standards. This compaction is done to achieve the maximum density achievable by the soil under dry conditions. After compaction, the sample is placed in a CBR test apparatus. The load is gradually applied to the soil sample, and the settlement (deformation) is measured. The CBR value is calculated based on the ratio between the applied load and the settlement that occurs.

RESULT AND DISCUSSION

Physical Properties

The results of soil physical properties consisting of Atterberg limits and sieve analysis can be seen in the following.

Table 8. Physical Properties of Original Soil Sample

Properties	Results
Liquid limit (%)	73,709
Plastic limit (%)	23,825
Plastic index (%)	49,884
Percent pass # 200) (%)	99,767

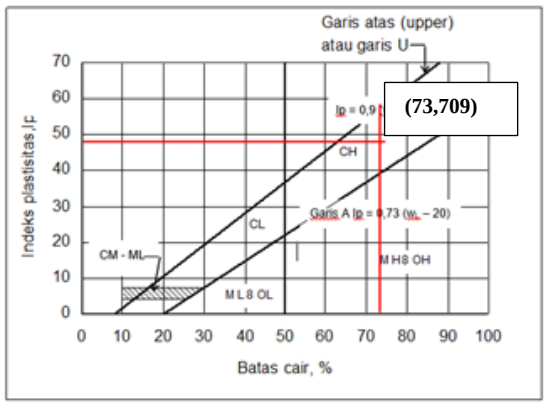

Figure 9: Liquid Limit with Plasticity Index

Visual observation of this soil has a dark yellowish-brown color, in a wet state the soil is very clayey and sticky. It can be concluded that the soil is clay. Classification according to AASHTO, that the soil that passes sieve number 200 (Ø 0.074 mm) is 99.767% more than 36%, so that the soil includes clay with group symbols A-4, A-5, A-6, and A-7.

Based on the liquid limit (LL) of 73.709% which is greater than 40% and plastic index (PI) of 49.884% which is greater than 11%, the soil belongs to group A-7. Group A-7 is also divided into groups A-7-5 and A-7-6. In cases where the plastic index equal to liquid limit is less than 30 (PI ≤ LL-30), the soil can be classified into group A-7-5, and if the plastic index equal to liquid limit is greater than 30 (PI > LL-30). The liquid limit, plastic index, and percentage of grains passing the 200 sieve form a group index that can be used to measure the quality of the soil. The group index value is 49.884. The results show that the soil in Glee Gurah Village belongs to the high plasticity clay soil group A-7-6 (47).

According to the USCS system, the determination of soil type is based on sieve analysis, liquid limit, and plastic limit. The results of the sieve analysis, which shows that the soil passing the 200 sieve has a value of 99.767% which is greater than 50%, and the liquid limit value, which shows 73.709% which is greater than 50%, indicate that the soil belongs to the MH, CH, and OH groups. Based on the graph using the liquid limit value of 73.709% and plastic index of 49.884%, the soil is classified into organic clay, with high plasticity (CH).

Table 8. Soil classification

Sample	Soil classification	
	AASHTO	USCS
Glee Gurah	A-7-5 (47) Clay soil with high plasticity	CH (Organic clay with high plasticity)

Soil Compaction Results

Soil compaction results show that proper compaction methods and the use of additives such as coconut shell ash can increase soil density and reduce undesirable development. Data from various studies show consistency in compaction results and soil development influenced by the number of impacts and additives used as shown in the table 9.

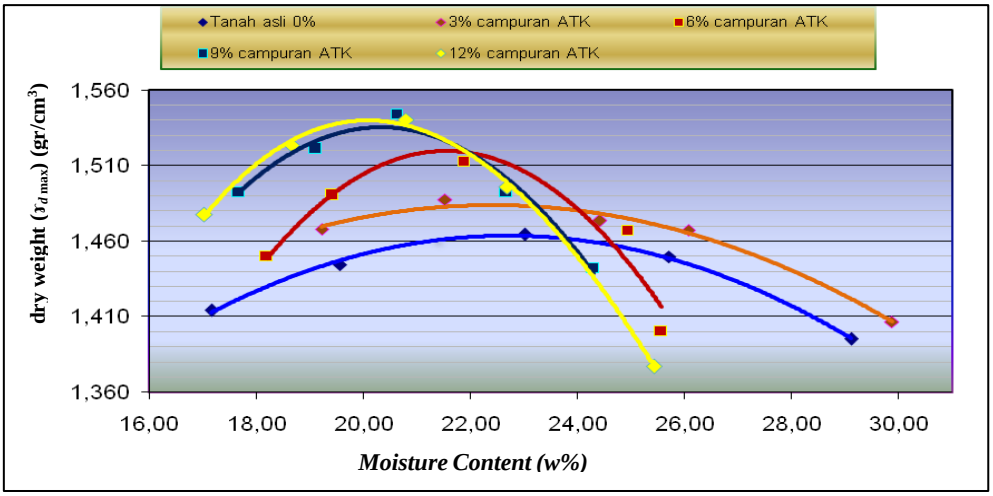

Figure 10. Graph of correlation between dry volume weight and moisture content

Table 9. Compaction Testing Results (Proctor)

Items	Original Soil	Variation of Mix Percentage			
		3%	6%	9%	12%
Maximum dry weight volume ($\gamma_{d\,maks}$) (gr/cm^3)	1,464	1,484	1,520	1,535	1,540
Optimum Moisture Content (%)	22,70	22,42	21,55	20,50	20,20

From the table 9, it can be seen that without soil admixture, the maximum dry volume weight is 1.464 gr/cm³. When varying percentages of admixture were added (3%, 6%, 9%, and 12%), the maximum dry volume weight increased gradually, reaching 1.540 gr/cm³ at 12% admixture. This increase indicates that the addition of admixtures can increase soil density, which can contribute to soil stability and strength. The optimum moisture content without admixture was 22.70%. When varying percentages of admixture were added, the optimum moisture content decreased gradually, reaching 20.20% at 12% admixture.

This decrease in optimum moisture content indicates that with the addition of admixtures, the soil becomes more efficient in achieving maximum compaction at lower moisture contents. This could be due to the better binding properties of the admixtures to the soil particles.

Overall, the compaction test results show that the addition of coconut shell ash increases the maximum dry volume weight and decreases the optimum moisture content, thus improving the quality and bearing capacity of clay soil as a highway subgrade.

CBR Testing Results

The test results show that the CBR value of the soil can be increased through proper stabilization techniques. The addition of coconut shell ash proved to be effective in increasing the bearing capacity of the soil. Higher CBR values not only indicate better soil conditions but also indicate the potential for more durable and stable road construction.

Table 10. CBR Test Results

Percentage (%)	Penetration (Inch)	CBR *Unsoakead*	CBR *Unsoakead (%)*
0%	0,2	11,06	
			15,58
3%	0,2	12,78	
			9,57
6%	0,2	14,00	
			9,52
9%	0,2	15,33	
			15,94
12%	0,2	17,78	
Total Percentage Increase in CBR			60,80

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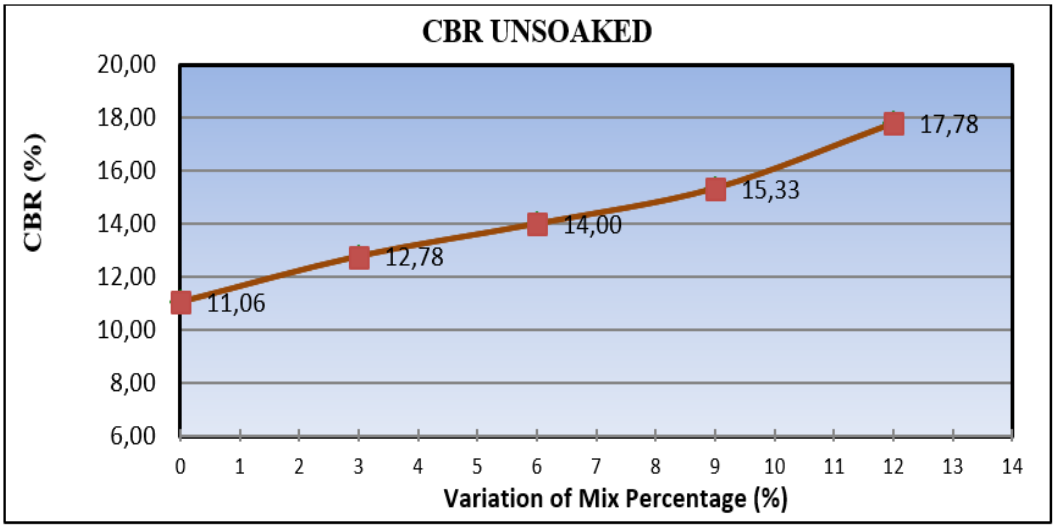

Figure 11. The correlation between coconut shell ash mixture content and unsoaked CBR

A measure of soil strength used to determine the ability of soil to support loads. The unsoaked CBR value is measured without the influence of moisture, which means the soil is tested in dry conditions.

From the table, it can be seen that the unsoaked CBR value increases as the percentage of coconut shell ash increases. **Figure 11**, the CBR test results shows the relationship between coconut shell ash content (X) and CBR value (Y). From the data given, it can be seen that the CBR value increases as the moisture content increases, which indicates that the soil becomes stronger at a certain moisture content. The CBR value increased from 11.06 at 0% to 17.78 at 12% coconut shell ash. This shows that the addition of coconut shell ash can increase the strength of the soil.

The Percentage of Unsoaked CBR Value shows the percentage change in the unsoaked CBR value compared to the CBR value at 0% coconut shell ash. From the table, it can be seen that the percentage increase in CBR varies, with the highest values at 9% and 12% of the mixture, indicating that the addition of coconut shell ash has a positive impact on soil strength.

In Figure 11, the CBR value increases with the addition of coconut shell ash mixture. This occurs because the elements contained in coconut shell ash such as Silica dioxide (SiO_2) and Calcium oxide (CaO) react to fill empty soil pores and the binding force between particles is getting bigger so that the pores in the soil decrease. The greater the addition of coconut shell ash causes the soil density to increase, the higher the CBR value and the greater the soil strength.

Statistical Analysis of the Effect of Coconut Shell Ash on Subgrade Stability

Based on the research data obtained, to find out the influence or differences from the variables used in this study, a statistical analysis was conducted using one-way ANOVA analysis.

The results of statistical analysis using one-way ANOVA test showed that there were significant differences in the CBR values, maximum dry volume weight, and optimum moisture content at various percentages of coconut shell ash addition (0%, 3%, 6%, 9%, and 12%). The p value obtained from the ANOVA analysis was <0.05, which indicated that the null hypothesis could be rejected, and at least one group had significantly different means.

Table 11. Test Effect of CBR Testing

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1431,94	2	715,97	1722,718	1,74809E-15	3,885294
Within Groups	4,987259	12	0,415605			
Total	1436,927	14				

The results showed that the addition of 12% coconut shell ash resulted in significantly higher CBR values compared to the other groups, with an increase in CBR values from 11.06% at 0% to 17.78% at 12%. In addition, the maximum dry volume weight also increased significantly, while the optimum moisture content decreased, indicating that the addition of coconut shell ash not only improved the bearing capacity of the clay soil, but also the soil compaction efficiency. These results confirm that the use of coconut shell ash as a stabilizing agent can effectively improve the quality of clay soil as a highway subgrade.

CONCLUSSION

The soil in Glee Gurah village is categorized as A-7-6 clay according to AASHTO, which means it has high plasticity. The sieve analysis results show 99.767%, more than 50%. While according to USCS, with a liquid limit of 73.709%, this soil is also included in the MH, CH, and OH groups, which means organic clay with high plasticity.

The compaction test results obtained the maximum dry volume weight before mixing with coconut shell ash was 1.464 gr/cm^3, while after adding coconut shell ash by 12% it became 1.540, but the optimum water content before adding the variation was 22.70% and after adding coconut shell ash it decreased by 20.20%. As the percentage of mixture increases, the maximum dry volume weight value tends to increase, while the optimum moisture content value tends to decrease. This shows that the addition of coconut shell ash mixture can increase the soil compaction ability, but it can also reduce the water content needed to achieve optimum compaction.

Referring to Table 4 regarding CBR values and subgrade strength, it can be concluded that the CBR value obtained (17.78%) indicates that the strength of the subgrade soil is classified as "Good". This means that normal compaction is not required, except for heavy traffic. Thus, the use of coconut shell ash as a construction material can contribute positively to subgrade strength, especially at higher moisture contents.

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