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COMBINATION OF COIR FIBER WASTE AND COIR-WOOD ASH FOR EXPANSIVE CLAY STABILIZATION

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ABSTRACT: Coir waste randomly mixed into soil is an alternative material for strengthening expansive clay. However, these materials cannot reduce swelling due to water, requiring chemical stabilization. This study combined coir fibers with a mixture of coir-wood ash, the waste from the tofu home industry. No studies have utilized such a combination of structural materials. This study aims to examine the soaked and unsoaked California Bearing Ratio (CBR), swelling, unconfined compressive strength (UCS), and tensile strength of soil mixed with 0.75% fibers, and ash with varying content: 0%, 2%, 4%, 6%, 8%, and 10% of the mixture's total weight. The curing time was seven days, 14 days, and 28 days. Testing refers to ASTM. The test results unveiled that the unsoaked CBR, soaked CBR, UCS, and tensile strength increased with rising ash content and curing time. A 6%–8% ash content produced the highest CBR, UCS, and tensile strength. On the other hand, by including a 6%–10% ash content, the swelling was decreased to 0%. Combining coir fiber and coir-wood ash has proven very effective for stabilizing expansive clays. In comparison to soils merely reinforced with fiber, the addition of coir-wood ash can eliminate swelling and increase the value of soaked CBR, UCS, tensile strength, and secant modulus up to 534%, 349%, 105%, and 824 %, respectively.

Keywords: Expansive Clay, Stabilization, Coir Fiber, Coir-Wood Ash, CBR, Unconfined Compressive Strength, Tensile Strength

1. INTRODUCTION

Soil is an essential component supporting the structure above it. However, the soil conditions sometimes do not meet the requirements, such as low bearing capacity, high compressibility, and sensitivity to water content changes, making such soil problematic. Expansive clay is one type of soil that belongs to this category. Stabilizing this soil physically, mechanically, and chemically can enhance its physical and geotechnical properties. Mechanical stabilization can be conducted by replacing, compacting, or strengthening the soil [1]. In contrast, chemical stabilization can be accomplished with the help of additives containing calcium, silica, or aluminum elements, such as lime, cement, fly ash, rice husk ash, or other chemical liquids [2-3]. These components would be influenced by the soil's physical and geotechnical properties due to a chemical reaction between them [4].

Due to its inherent characteristics, soil stabilization utilizing coconut coir waste is considered an alternative method. This organic material, which is lightweight, biodegradable, eco-friendly, and affordable in numerous Asian countries, has been developed and utilized as a stabilizing agent [5-8]. Coir contains 75% fibers and 25% cork (pitch), a binder between fibers. Coir fibers contain 35%-45% lignin and 23%-43% cellulose [5]. Coir fibers have a relatively high tensile strength of up to 220 MPa and can maintain stability when wet. They possess the highest strain among other fibers, 15%-30% [9]. Compared to synthetic fibers, coir fibers are more elastic and have a higher coefficient of friction [10-11]. So far, coconut coir waste has been employed as handicraft materials and household appliances [12]. In addition, the tofu home industry utilizes coconut fibers mixed with wood as fuel.

Several studies have been done by many researchers and shown that coir waste is helpful as a soil-reinforcing material. The soil's mechanical properties experienced a significant improvement [13-28]. Randomly incorporating fibers enhances soil properties such as shear strength, bearing capacity, and tensile strength. This improvement occurs due to the interaction between the fibers and the soil, primarily based on adhesion. As a result, therefore, the soil becomes more flexible and resilient, exhibiting characteristics of more excellent ductility [29-30]. However, the fibers could not reduce the swelling caused by water [31]. Therefore, the mixture should be combined with the chemical stabilizer. Finally, the results revealed that soil mixed with coir ash enhanced the soil's physical and mechanical properties [32-33].

Soil stabilization was determined by ash content and curing time [34].

2. RESEARCH SIGNIFICANCE

Research on a combination of coir fiber and coir-wood ash waste as a structural material is currently not found. Therefore, in this study, soil stabilization was carried out using a variety of 0.75% coir fiber (the result of previous research) and coir-wood ash with varying content to improve the mechanical properties of the soil, especially the unsoaked California Bearing Ratio (CBR), soaked CBR, swelling, unconfined compressive strength (UCS), and tensile strength. These two additional materials are expected to provide an alternative improvement for expansive clay that is more environmentally friendly, easy to obtain, and economical.

3. MATERIAL AND METHOD

3.1 Materials

This study utilized expansive clay, coir waste, and a mixture of coir-wood ash waste as stabilizing agents. The physical and mechanical properties data were obtained from the results of previous studies, as presented in Table 1.

Table 1 The physical and mechanical properties of expansive clay [28, 31]

Parameter	Result
Specific Gravity, G_s	2.63
Liquid Limit, LL	89.91%
Plastic Limit, PL	38.86%
Plasticity Index, PI	51.05%
Shrinkage Limit, SL	16.22%
Maximum Dry Density, MDD	12.64 kN/m^3
Optimum Moisture Content, OMC	29.9%
Coarse Grain (sand)	13.36%
Fine Grain (silt and clay)	86.64%
Soil Classification (USCS)	CH
Soil Classification (AASHTO)	A-7-6
Activity (Skempton)	3.18 (active clay)
Unsoaked CBR	4.29%
Soaked CBR	1.25%
Swelling	0.96%
Unconfined Compressive Strength (UCS)	41.70 kPa
Tensile Strength	18.61 kPa

Fiber waste from coconut coir was obtained from traditional markets. The fibers were cut into 30mm-50mm pieces and mixed randomly into the soil until evenly distributed. Table 2 exhibits the tensile strength of coir fibers.

Table 2 The tensile strength of coir fibers

Sample	Length (mm)	Diameter (mm)	Strain (%)	Tensile strength (MPa)
1	100	0.0208	32.60	121.6
2	100	0.0272	30.97	225.0
3	100	0.0313	20.53	240.8
4	100	0.0319	27.80	107.4
5	100	0.0411	34.10	147.2
Average	100	0.0305	29.20	168.4

Ash was gathered from the tofu home industry waste, particularly from the wood and coir fibers burned throughout the process. The selected ash was gray and passed sieve number 200. The coir-wood ash was examined for chemical elements at the GetIn Laboratory-CICERO of the Faculty of Engineering of Universitas Gadjah Mada, indonesia. Table 3 summarizes the chemical elements of coir-wood ash. The result portrays that coir-wood ash contained chemical elements commonly discovered in materials classified as pozzolans.

Table 3 Chemical elements of coir-wood ash

Element	Concentration
SiO_2	33.52%
CaO	27.58%
K_2O	15.23%
MgO	4.97%
P_2O_5	3.95%
Cl	3.71%
SO_3	3.67%
Al_2O_3	1.93%
Na_2O	1.21%

3.2 Mixture Design of Specimens

The clay was mixed with coir fibers with a fixed content of 0.75% of the mixture's total weight (based on the results of previous studies) [28] and ash with varying content, as presented in Tables 4 and 5.

Soil, fibers, ash, and water were weighed following the mixture design and stirred until evenly distributed. Specimen compaction required data on MDD and OMC values of the clay soil.

The CBR specimens were cylindrical with a 15.24 cm diameter and a 17.78 cm height. The specimens were previously soaked in water for four days to determine their strength at the worst subgrade condition (for the soaked CBR). Meanwhile, the UCS specimens were cylindrical with a 3 cm diameter and 7 cm height. Furthermore, the tensile strength specimens were cylindrical with a 7 cm height and a 3.5 cm diameter.

Table 4 The variations and curing time design of the unsoaked CBR, soaked CBR, and swelling specimens

Specimen's Variation		Unsoaked CBR, Soaked CBR, and Swelling (days)	
		7	14
The soil was mixed with 0.75% coir fibers and ash with varying content	2%	●	●
	4%	●	●
	6%	●	●
	8%	●	●
	10%	●	●

Table 5 The variations and curing time design of the UCS and tensile strength specimens

Specimen's Variation		UCS and Tensile Strength (days)	
		14	28
The soil was mixed with 0.75% coir fibers and ash with varying content	2%	●	●
	4%	●	●
	6%	●	●
	8%	●	●
	10%	●	●

3.3 Testing Procedure

All tests were conducted at the Geotechnical Laboratory of the Civil Engineering Department of Universitas Muhammadiyah Yogyakarta, Indonesia, from June 2022 to March 2023.

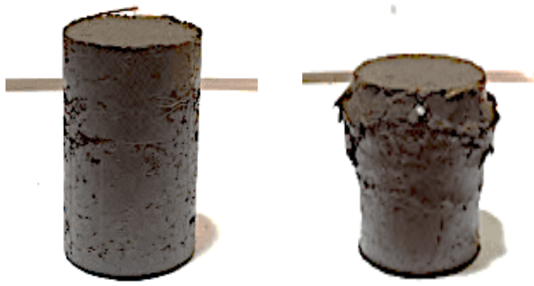
The CBR tests were carried out based on ASTM D1883-07e2 [35]. Static load was applied gradually to the specimens until the displacement reached 12.7 mm (0.5 inches) (Fig. 1).

The unconfined compressive strength test standard followed ASTM D2166-06/D2166 M-16 [36]. Axial loading was given until the specimens collapsed or the strain reached 15%. Fig. 2 illustrates the sample before and after testing.

The tensile strength was the subsequent test performed. Axial loading was provided continuously until the specimens cracked or collapsed (Fig. 3). The test utilized an unconfined compressive strength machine under ASTM C 496/C 496M – 04 [37]. Static load was gradually applied at a constant rate of 0.96 MPa/min until the failure of the specimens.

(a) (b)

Fig. 1 (a) Swelling test (b) CBR test



(a) (b)

Fig. 2 Specimen (a) before testing, (b) after testing

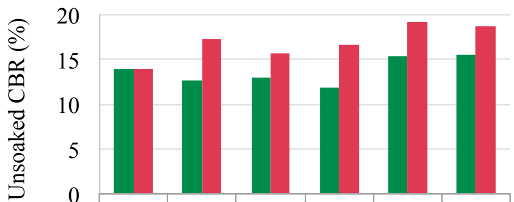
(a) (b)

Fig. 3 (a) Tensile strength test (b) Specimen after testing.

4. RESULTS AND DISCUSSION

4.1 Effect of Ash Content on the Unsoaked CBR and Soaked CBR of Mixed Soil

Fig. 4 depicts the test results on clay's unsoaked CBR and soaked CBR stabilized with 0.75% coir fibers and ash with various content.

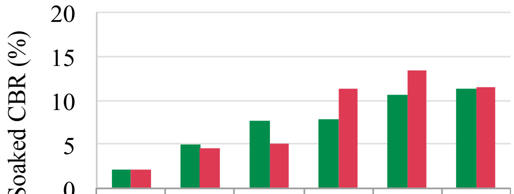


	0	2	4	6	8	10
7 days	13.92	12.70	12.93	11.82	15.35	15.54
14 days	13.92	17.24	15.63	16.68	19.23	18.64

Ash Content (%)

7 days 14 days

(a)



	0	2	4	6	8	10
7 days	2.12	4.98	7.60	7.79	10.56	11.23
14 days	2.12	4.54	5.13	11.28	13.44	11.52

Ash Content (%)

7 days 14 days

(b)

Fig. 4 Effect of ash content on the CBR of mixed soil with seven days and 14 days of curing (a) unsoaked CBR, (b) soaked CBR

Expansive clay acquired an unsoaked CBR value of 4.29% and a soaked CBR value of 1.25% (Table 1). Fig. 4 demonstrates that after being reinforced with 0.75% coir fibers, the CBR values escalated to 13.92% (unsoaked) and 2.12% (soaked). Adding fiber reinforcement causes an interaction between the coir fiber surface and the soil matrix.

Adding ash increased the unsoaked CBR and soaked CBR values as the ash content rose. Adding a 10% ash content produced the maximum CBR value for the seven-day curing time. However, at 14 days of curing, the optimum CBR value was obtained by adding an 8% ash content. The unsoaked CBR and soaked CBR values of fiber-reinforced and ash-stabilized soils increased by 38% and 534%, respectively, from the CBR values only reinforced with coir fiber.

Table 3 depicts that the coir-wood ash contained 33.52% SiO_2 and 27.58% CaO. As Situmorang asserted, CaO has the same content as Quicklime. Quicklime possesses cement-like properties that can harden when mixed with water. The clay structure comprised silica (Si) layers. A chemical crystallization reaction emerged when clay and ash were combined [40].

$CaO + H_2O \rightarrow Ca(OH)_2 + heat$

$Ca(OH)_2 + SiO_2 + H_2O \rightarrow Ca(SiO_3) + 2H_2O$

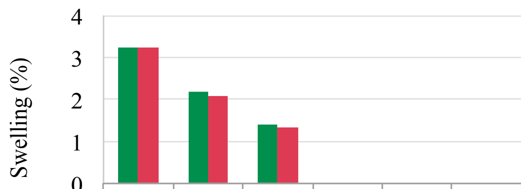
This chemical reaction is similar to cement hardening, which occurs continuously for months. This process is called pozzolanization.

There was a decrease in the CBR value with the addition of a 10% ash content. These results align with those of Yusuf and Zava's research. The reduction in the CBR value for an ash content of more than 8% was caused by the increased soil porosity, thereby raising compressibility and reducing soil strength [33]. Ikeagwuani stated that the decline in CBR value could be attributed to the formation of potassium feldspar, where all the K+ ions in the ash have been used up, resulting in soil flocculating. This flocculation enlarged particle size and voids, reducing soil strength [38].

Bowles classified soil based on the CBR value [39]. The unsoaked CBR value belonged to the "poor" level before being stabilized. In contrast, its level increased to "fair" after being stabilized with coir fibers and variations in ash content. Similarly, the soaked CBR value was "very poor" before being stabilized. However, after being stabilized with coir fibers and variations in ash content, it fell into the "poor-fair" level.

4.2 Effect of Ash Content on the Swelling of Mixed Soil

Fig. 5 exhibits the test results on the clay's swelling stabilized with 0.75% coir fibers and ash with various content.



	0	2	4	6	8	10
7 days	3.25	2.17	1.41	0.00	0.00	0.00
14 days	3.25	2.07	1.35	0.00	0.00	0.00

Ash Content (%)

7 days 14 days

Fig. 5 Effect of ash content on the swelling of mixed soil with seven days and 14 days of curing

Fig. 5 illustrates that with seven days and 14 days of curing, the swelling value dropped with increasing ash content. Adding a 6%, 8%, and 10% ash content declined the swelling value to 0% (100% reduction). A significant decrease in swelling is caused by the chemical reaction of the soil particles with the additive, causing flocculation and cementation of the clay particles. This process causes the soil particles to become larger, and the surface of the particles is rougher and less plastic. As a result, these enlarged granules minimized the swelling [32, 41].

4.3 Effect of Ash Content on the Unconfined Compressive Strength of Mixed Soil

Fig. 6 displays the test results on the clay's unconfined compressive strength (UCS) stabilized with 0.75% coir fibers and ash with various content.

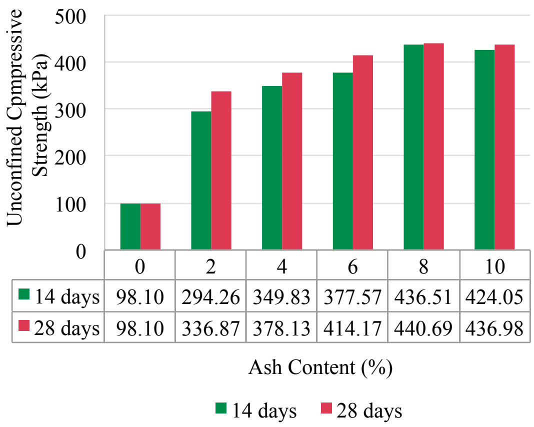


Fig. 6 Effect of ash content on the unconfined compressive strength of mixed soil with 14 days and 28 days of curing

Fig. 6 demonstrates a similar trend between the UCS and CBR results. The UCS value increased significantly with rising ash content. It reached an optimum value of 440.69 kPa in soil with a 0.75% coir fiber content and an 8% ash content at 28 days of curing (an increase of 349% from soil reinforced only with coir fibers). The UCS value increased due to cementation between soil and ash, causing agglomeration and strengthening the bond between grains. The existing voids were partially surrounded by a more rigid cementation material, causing the granules not to be easily crushed and more difficult for water to penetrate. However, adding a 10% ash content declined the UCS value. Formed coarser particles will occupy a larger space in the soil matrix, thereby increasing the volume of voids and reducing the dry density of the mixture. Low density causes loss of friction and cohesion between particles [32-33].

The consistency of clay soil was classified based on the UCS value [42]. Table 1 exhibits that the clay soil without stabilization acquired a UCS value of 41.70 kPa, belonging to the category of "soft" soil. After being reinforced using 0.75% coir fibers, the UCS value increased to 98.10 kPa, classified as "medium" soil. Stabilization was carried out by combining coir fibers and coir-wood ash. The soil was "very stiff" at a 2%-6% ash content and "hard" at 8%-10%.

4.4 Effect of Ash Content on the Modulus Secant of Mixed Soil

The secant modulus (E_{50}) is a method to determine soil stiffness or elasticity. This elastic modulus refers to the stress value of the specimen at half of the peak compressive strength (q_{50}) and the strain at the q_{50} value. Fig. 7 displays the graph of the secant modulus value of the mixed soil.

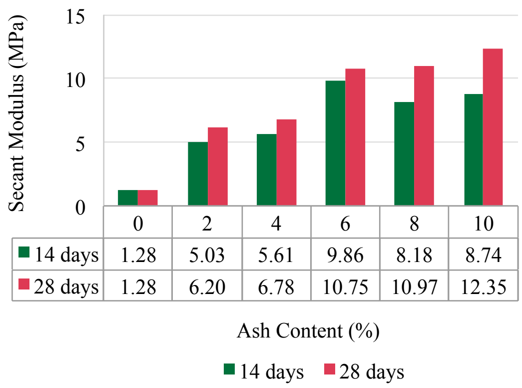


Fig. 7 Effect of ash content on the modulus secant of mixed soil with 14 days and 28 days of curing

Fig. 7 illustrates that the secant modulus value escalated as the ash content was added. A mixture of 10% ash generated the maximum secant modulus value of 12.35 MPa at 28 days of curing (an increase of 865% from soil reinforced only with coir fibers).

4.5 Effect of Ash Content on the Tensile Strength of Mixed Soil

Fig. 8 depicts the test results on the tensile strength of clay stabilized with 0.75% coir fibers and ash with various content.

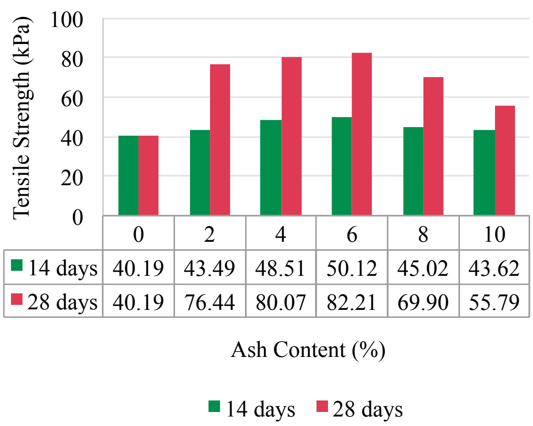


Fig. 8 Effect of ash content on the tensile strength of mixed soil with 14 days and 28 days of curing

Table 1 illustrates that unreinforced clay acquired a tensile strength of 18.61 kPa. Fig. 8 demonstrates a tensile strength increase to 40.19 kPa after being reinforced with coir fibers. After stabilization with ash, the tensile strength rose with increasing ash content. It reached an optimum value of 6% at 28 days of curing, which was 82.21 kPa (a 105% increase over coir fiber-reinforced clay). The increase in tensile strength is not as significant as in the CBR and UCS value. The main tensile strength is due to the fibers' tensile strength, which helps hold the soil particles when moving horizontally. The presence of fiber also increases the contact area between the fiber surface and the soil grains, thus increasing the friction between them.

4.6 Effect of Curing Time on the Mechanical Properties of Mixed Soil

Fig. 4 to Fig. 8 depict that curing time affected the mechanical properties of mixed soil. The longer the curing time, the higher the soil's mechanical properties. According to Lapian and Rochmawati, the longer the curing time on the specimen, the longer the cementation process [43]. As a result, the soil's density rose, increasing the CBR, UCS, and tensile strength but declining the soil's swelling.

5. CONCLUSION

As the ash content and curing time increase, the combination of clay reinforced with coir fibers and stabilized with coir-wood ash demonstrates improvements in unsoaked CBR, soaked CBR, unconfined compressive strength (UCS), and tensile strength.

A 6%–8% ash content produced the highest CBR, UCS, and tensile strength. On the other hand, by including a 6%–10% ash content, the swelling was decreased to 0%. Combining coir fiber and coir-wood ash has proven very effective for stabilizing expansive clays. In comparison to soils merely reinforced with fiber, the addition of a fiber-wood ash combination can raise the values of soaked CBR, UCS, tensile strength, and secant modulus by up to 534%, 349%, 105%, and 865%, respectively.

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