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Increasing Unconfined Compressive Strength of Soft Clay Stabilized with Coir Fiber and Bagasse Ash Mix

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A B S T R A C T

Increasing coir fiber and bagasse ash waste can cause environmental degradation. Utilization of this waste in construction work is still rarely done. Coir fiber is a natural material with the highest coefficient of friction and tensile strength. Bagasse ash has a high silica content and is suitable for use as pozzolan. Soil stabilization with a combination of both is expected to improve the geotechnical properties of soft soil. This research aims to analyze the unconfined compressive strength (UCS) and secant modulus of soft clay stabilized with coir fiber-bagasse ash mix. Coir fiber as much as 0.75% and ash with varying contents: 0%, 2%, 4%, 6%, 8%, and 10% of the total weight of the mixture. The specimens were cured for 28 days. UCS tests were conducted according to ASTM D2166-16 with the axial stress and strain relationship curve results to determine the UCS and secant modulus. The results showed that the UCS value and secant modulus value increased along with increasing bagasse ash content. The maximum value was achieved at 8% ash variation with a UCS value of 472.45 kPa (an increase of 382% from a soil-coir fiber mix) and a secant modulus value of 21.94 MPa (an increase of 571% from a mixture of soil and coir fiber). The research results show that this mixed soil is classified as hard soil, which can withstand high loads. It is hoped that the results of this research can become a reference for stabilizing soft soil in the field.

1. Introduction

Soil is essential in construction because it functions as a load support and transmits this load to a particular layer or depth. The condition of the existing soil influences the strength

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A. Widianti / U Karst Vol. 08 No. 01 Year 2024 ISSN (*Print*) 2502-9304

of the structure above. 10% of Indonesia's land area is soft clay and peat soil [1]. High water content, high degree of saturation, high initial pore water pressure, high pore ratio, and porosity are characteristics of soft soil [2]. Because of this, the soil might harm the structure above it due to its low shear strength, limited bearing capacity, and excessive compressibility.

If the compressive strength of the soil is less than 50 kPa, it can be classified as soft clay [3]. As a result, soil stabilization is required to enhance the soil's mechanical and physical characteristics. Soil stabilization can be achieved chemically by mixing cement, lime, and other ingredients or mechanically by utilizing reinforcement. The ingredients must be combined with it in the right amounts to enhance the soil quality [4].

According to data from the Food and Agriculture Organization (FAO), in 2022, Indonesia will be ranked 1st in the world's largest coconut producer, 17.19 million tons. It is ranked 8th in the world as the largest producer of sugar cane, namely 32.40 million tons [5]. 35% of coconut is coir, which will become waste [6], while the average amount of bagasse waste reaches 90% every time sugar cane is processed [7]. This waste can cause environmental pollution, especially in the surrounding disposal area. Therefore, soil stabilization using plant waste is one solution to reduce potential environmental damage and save costs [8][9].

Numerous studies have used coir fiber reinforcement. Of all the natural fibers, coir fiber has the highest tensile strength [10]. By incorporating coir fibers at random into the soil, the fibers and the soil will have a larger surface area to touch with, enhancing their interaction and interlocking and strengthening the soil to bear the imposed load [11][12]. The California Bearing Ratio (CBR) [13][14], shear strength [15][16], tensile strength [17], and unconfined compressive strength (UCS) [18][19] have all risen in soft soil reinforced with coir fiber.

According to studies by Sujatha et al. and Himanshu et al., maximum UCS was obtained in soil reinforced with 0.75% coir fiber[11], [20]. Research by Widianti et al. shows the same results. UCS peaks at a coir fiber percentage of 0.75%, with a value of 98.10 kPa. The strength decreases when the percentage of coir fiber is more than 0.75%[21]. Several UCS tests have also been carried out using a combination of coir fiber reinforcement and chemical stabilization. The stabilizer materials used include rice husk ash [22][23], coir-wood ash [24], fly ash [25][26][27], and lime [28][29]. Singh and Kalita combined coir fiber and bagasse ash to stabilize expansive soils in India. The soil was mixed with 0% to 20% bagasse ash and reinforced with coir fiber with 0.5% and 1.0% content. The tests carried out are liquid limit, plastic limit, free swelling index, and UCS. Maximum results are obtained in soil mixed with 10% bagasse ash and 0.5% coir fiber [30].

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Bagasse ash is the byproduct of burning bagasse, obtained from sugar industry trash during the sugar cane milling [31]. Because bagasse ash possesses pozzolanic qualities and a high silica (SiO_2) content, it can be utilized as a material for stabilizing soil [32][33]. The lime percentage (CaO) contained in bagasse ash is also an essential element in the pozzolanic reaction in the soil stabilization process [34]. Adding cement and bagasse ash to the soil causes the clay grains to enlarge, increasing the friction angle value in the soil, which increases the soil's UCS [35].

No research has focused on combining coir fiber and bagasse ash as a stabilizer for soft clay. This research aims to analyze the behavior of soft clay reinforced with coir fiber and stabilized with bagasse ash and determine the optimal mixture that produces maximum results. The behavior observed includes the relationship between compressive stress and strain, UCS, and secant modulus (E_{50}). It is hoped that the results of this research can be a reference for stabilizing soft soil in the field.

2. Research Method

This experimental research was conducted at the Geotechnical Laboratory of Universitas Muhammadiyah Yogyakarta. The research begins by preparing materials and equipment. Next, mix designs are prepared for various mix variations. The ingredients are weighed according to the mix design, stirred, and water is added until evenly distributed. All materials are compacted into a mold and then cured for 28 days. The next step is the UCS test using the Digital Unconfined Compressive Strength Test Machine, which refers to ASTM D2166-16 [36]. The resulting output is the load and axial deformation values. This data produces a relationship curve between axial stress and strain to determine the maximum stress for each variation of bagasse ash. The secant modulus was also analyzed to determine the best mixture percentage applied in the field.

2.1 Materials

The materials used in this research were clay, coir fiber, and bagasse ash (**Figure 1**). The clay soil from Kulon Progo, Yogyakarta. The soil was crushed using a hammer to pass the No.40 sieve (size < 0.425 mm), then oven for 16-24 hours at a temperature of 105-110°C to dry the soil. Widianti et al. have tested this soil's physical and mechanical properties in a previous study [21].

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ISSN (*Online*) 2581-2157
A. Widianti / U Karst Vol. 08 No. 01 Year 2024 ISSN (*Print*) 2502-9304

(a) (b) (c)

Source: Research Dokumentation (2023).

Figure 1. Materials (a) Clay, (b) Coir Fiber, (c) Bagasse Ash.

The results of the physical property test conducted by ASTM were Specific Gravity (Gs) = 2.63, Liquid Limit (LL) = 89.91%, Plastic Limit (PL) = 38.86%, Shrinkage Limit (SL) = 16.33%, and Plasticity Index (PI) = 51.05%. According to USCS, the soil is classified as clay with high plasticity (CH), while according to AASHTO, the soil is classified as A-7-6. The results of mechanical property testing according to ASTM included an Optimal Moisture Content (OMC) of 29.9%, a Maximum Dry Density (MDD) of 12.8 kN/m^3, and an Unconfined Compressive Strength (UCS) of 41.70 kPa [21].

Coir fiber waste was obtained from selling coconut milk at traditional markets in Yogyakarta. The fibers are cut into 50mm lengths, making mixing evenly with the soil easier. Coir fiber has a tensile strength between 107.4 MPa and 240.8 MPa, with a strain between 20.5% and 34.1%.

Bagasse ash waste is taken from burning it at the Madukismo Sugar Factory, Bantul, Yogyakarta. The ash passing No. 200 sieve (<0.075 mm) was then placed in an oven at a temperature of 105-110^{o}C within 16-24 hours to dry the ash. Bagasse ash has been tested for its chemical elements at the GetIn-CICERO Laboratory, Department of Geological Engineering, Gadjah Mada University, as shown in **Table 1**. Bagasse ash has a very high percentage of SiO_2, namely 81.12%.

Table 1. Chemical Elements of Bagasse Ash.

Element	Concentration
SiO_2	81.12%
Al_2O_3	6.18%
Fe_2O_3	5.35%
CaO	4.28%
K_2O	3.07%

Source: Test Result (2023).

ISSN (*Online*) 2581-2157
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The coir fiber content is 0.75% (based on research results by Widianti et al.)[21], while the bagasse ash content varies between 0%-10% of the specimen's total weight. **Table 2** displays the mixed design of the specimens.

Table 2. Mix Design of Specimens.

Code	Fiber Percentage (%)	Ash Percentage (%)	Dry Soil Weight (grams)	Fiber Weight (grams)	Ash Weight (grams)	Water (ml)	Number of Specimens
A	0	0	86.21	0	0	25.78	2
B	0.75	0	85.56	0.65	0	25.78	2
C	0.75	2	83.83	0.65	1.73	25.78	3
D	0.75	4	82.11	0.65	3.45	25.78	3
E	0.75	6	80.39	0.65	5.17	25.78	3
F	0.75	8	78.66	0.65	6.90	25.78	3
G	0.75	10	76.94	0.65	8.62	25.78	3

Source: A and B: Widianti et al. (2021) [21]*; C, D, E, F, and G: Research Method (2023).*

2.2 Testing Procedure

The specimen mold measures 35 mm in diameter and 70 mm in height. The primary equipment used is the Digital Unconfined Compressive Strength Test Machine equipped with a computer (**Figure 2**). The equipment speed is set at 1%. **Figure 3** shows the specimen after the UCS test.

Source: Research Documentation (2023).

Figure 2. Process of Testing

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ISSN (*Online*) 2581-2157
A. Widianti / U Karst Vol. 08 No. 01 Year 2024 ISSN (*Print*) 2502-9304

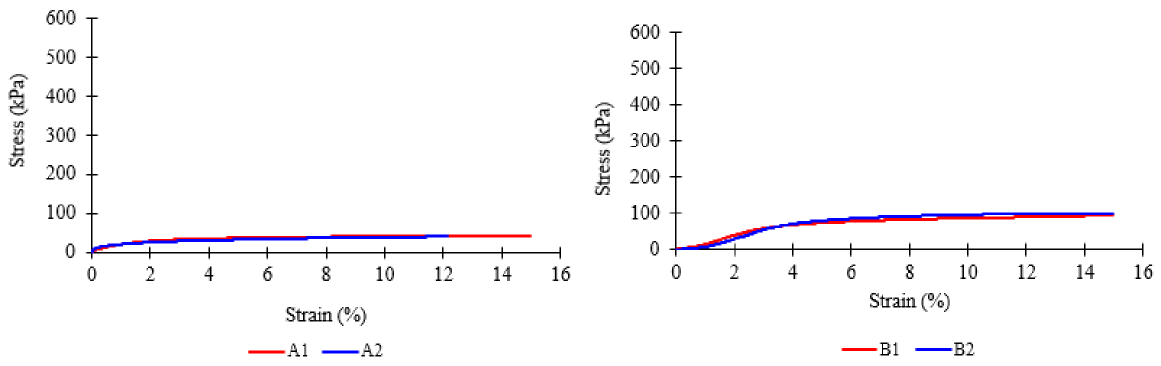
Source: Research Documentation (2023).

Figure 3. Specimen After Testing

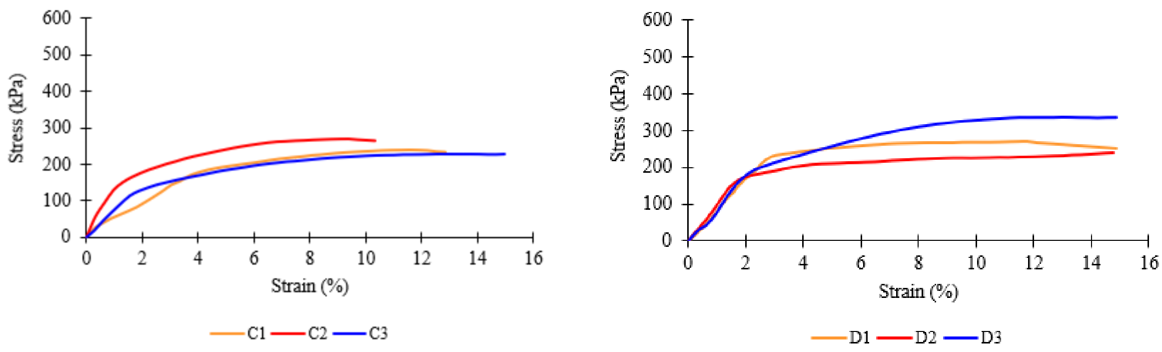
3. Results and Discussions

3.1 Unconfined Compressive Strength

The unconfined compressive strength (UCS) test shows the relationship between axial stress and strain. **Figure 4** displays the results of the UCS test conducted on a soil-coir fiber mixed with varying content of bagasse ash. ASTM stated that the UCS value is the highest value of axial stress, which a cylindrical specimen can withstand without collapsing or undergoing 15% axial strain [36].



(a) (b)



(c) (d)

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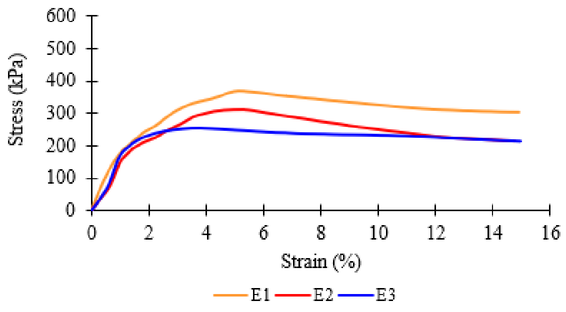
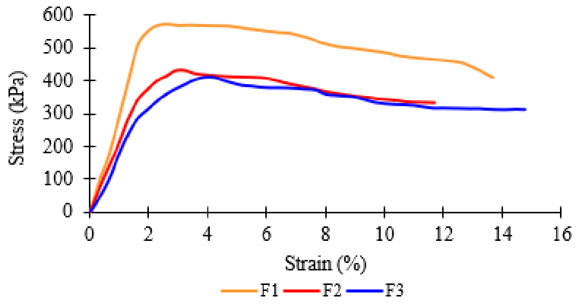
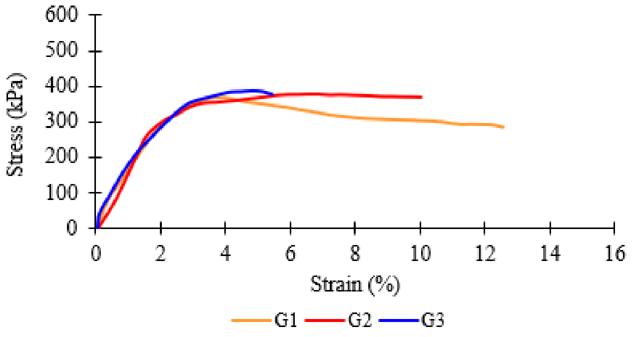


(e)



(f)



(g)

Source: (a) and (b): Widianti et al. (2021) [21]*; (c), (d), (e), (f), and (g): Data Analysis (2023).*

Figure 4. Results of the UCS Test (a) Soil; (b) Soil with Coir Fiber 0.75%; (c) Soil with Coir Fiber 0.75% and Bagasse Ash 2%; (d) Soil with Coir Fiber 0.75% and Bagasse Ash 4%; (e) Soil with Coir Fiber 0.75% and Bagasse Ash 6%; (f) Soil with Coir Fiber 0.75% and Bagasse Ash 8%; (g) Soil with Coir Fiber 0.75% and Bagasse Ash 10%.

Figure 4 shows that the soil reinforced with coir fiber and stabilized using bagasse ash (**Figure 4c-4g**) has higher peak stress compared to the soil (**Figure 4a**), and the soil is only reinforced with coir fiber (**Figure 4b**). The bagasse ash will react with the soil and produce a material that increases the strength of the mixture. Materials containing silica or silica and alumina can become pozzolan materials, including rice husk ash and fly ash. When this material reacts with water, it becomes rigid and compact [37]. Bagasse ash has a very high SiO_2 percentage (81.12%) and sufficient CaO percentage (4.29%). Clay soil composition is dominated by silica and aluminum elements [3]. In clay stabilized with bagasse ash, a reaction will occur to form calcium hydrate (C-S-H), calcium silicate hydrate (C-S-A-H), or calcium aluminate hydrate through the bond between CaO plus water plus Al_2O_3 and SiO_2, which is called the pozzolan reaction. This reaction happens because the hydrating compound is in gel form and will harden over time. This process is the same as previous research, which used a combination of coir fiber and rice husk ash or fly ash to stabilize the soil [22][23][26][27].

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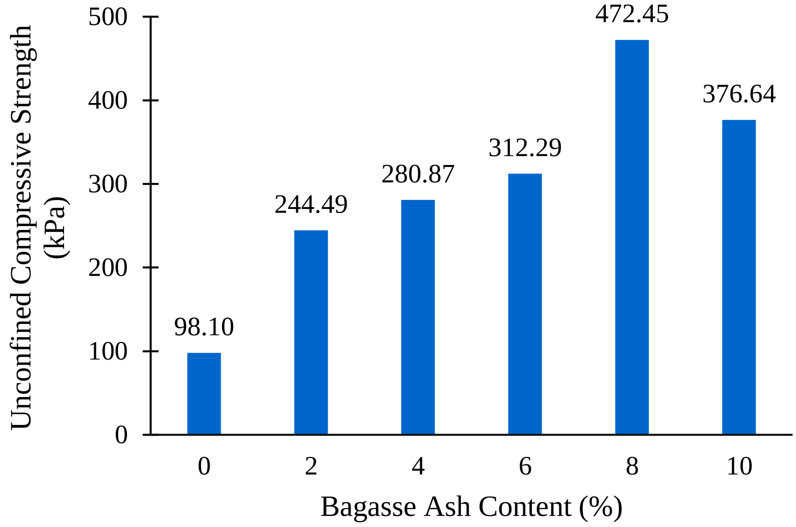
Figure 4 also shows that the presence of fibers in the soil causes the specimen to tend to be ductile, as shown in the resulting strain graph. Coir fibers have a high friction coefficient. The friction between the soil particles and the fiber surface randomly dispersed into the soil in a certain amount will increase the soil's shear strength and bearing capacity [38]. The fiber also has a high tensile strength. When the soil grains shift horizontally, the fibers will help in resisting because of their tensile strength [39].

Based on **Figure 4**, the UCS value obtained from the maximum stress value can be determined. **Figure 5** displays the values.



Source: Data Analysis (2023).

Figure 5. Effect of Bagasse Ash Content on The UCS of Clay Soil-Coir Fiber Mix.

Initially, the UCS value of clay was 41.70 kPa [21]. This soil was classified as soft soil [3] and needs stabilization. Widianti et al. reinforced the soil using coir fiber, and the UCS value reached a maximum in soil reinforced with 0.75% coir fiber. The UCS value increased to 98.10 kPa (an increase of 135.25% from unreinforced soil) [21]. The soil was classified as medium soil [3]. Figure 5 shows that the UCS value increases after stabilizing with a combination of 0.75% coir fiber and bagasse ash. The UCS value increases along with the increasing content of bagasse ash added and reaches the maximum value in soil with 0.75% fiber added and 8% bagasse ash, namely 472.45 kPa (an increase of 382% compared to soil reinforced with coir fiber only). Hardiyatmo [3] states that soil with a UCS value > 400 kPa was classified as hard soil. Hence, its ability to support loads is very high. The UCS value decreased after the ash percentage was increased to 10%. At this ash percentage, the soil grains enlarge, so the pores enlarge. If it is filled with water, the moisture content increases and soil density decreases [4]. However, this value is still much higher than the soil's, only reinforced with coir fiber.

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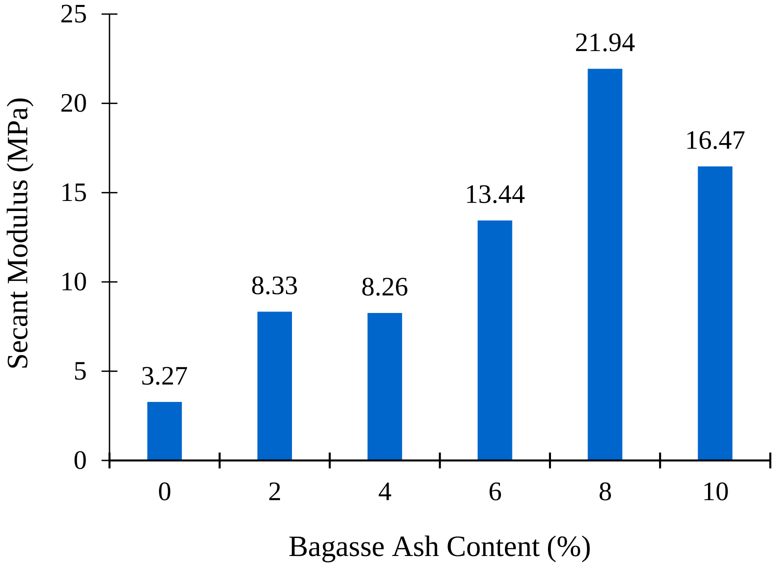
3.2 Secant Modulus

One of the parameters often used to evaluate material stiffness is the secant modulus (E_{50}). E_{50} is the value of the stress resistance of the specimen at 50% before deformation. The secant modulus value can be calculated from the results of the UCS soil test with added coir fiber and ash. **Figure 6** illustrates the graph of the secant modulus.



Source: Data Analysis (2023).

Figure 6. Effect of Bagasse Ash Content on The Secant Modulus of Clay Soil-Coir Fiber Mix.

Figure 6 shows that the soil with 0.75% coir fiber has the smallest E_{50} among the other mixed specimens. E_{50} increases from 3.27 MPa to 21.94 MPa (an increase of 571% from a soil-coir fiber mix). Obrzud and Truty state that clay with high plasticity (CH), which has an E_{50} value between 20-32 MPa, can be classified as hard soil [40]. According to Muntohar, clay soil that is chemically stabilized will experience three reaction processes, namely cation exchange, flocculation and agglomeration, and pozzolan reaction [37]. Bagasse ash contains the chemical element SiO_2, which is relatively high, which causes this material to have high pozzolanic properties. If it reacts with alumina compounds such as Al_2O_3 and CaO in clay soil, it will produce hard soil, increasing its stiffness [41].

4. Conclusions

The results showed that the UCS value and secant modulus increased along with the increase in bagasse ash content. The maximum value was achieved at 8% ash variation with a UCS value of 472.45 kPa (an increase of 382% from a soil-coir fiber mix) and a secant modulus

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value of 21.94 MPa (an increase of 571% from a soil-coir fiber mix). The research results show that adding 0.75% coir fiber and 8% bagasse ash can change soft soil into hard soil that can withstand high loads. It is hoped that the results of this research can become a reference for stabilizing soft soil in the field.

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