Unconfined Compressive Strength of Clay Strengthened by Coconut Fiber Waste

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ABSTRACT
Indonesia is a country that produces the largest coconut in the world. 35% of the coconut volume is coir. Coir is a waste that has not been widely used for construction work. The coir fibers have the highest tensile strength among other natural fibers and have resistance to compressive forces. In this study, the unconfined compressive strength (UCS) of clay strengthened with coconut fiber is presented. The specimens were made with the fiber percentage of 0.00%; 0.25%; 0.50%; 0.75%; and 1.00% by weight of the mixture. This study concluded that the clay's UCS has increased along with the more coconut fiber added. The maximum value of UCS and secant modulus was obtained in clay with fibers of 0.75%. The clay strengthened with coconut fiber becomes stiffer than the initial clay, thereby improving its soil stability.

Keywords—clay, unconfined compressive strength, secant modulus, coconut fiber

1. INTRODUCTION

Clay is one type of soil that is less profitable because it is highly influenced by moisture content, has low permeability, low bearing capacity, and slow consolidation process. Therefore, it is necessary to stabilize the soil to improve its physical and mechanical properties. Many studies currently utilize waste from natural materials as reinforcement materials or additives mixed into the soil to increase its strength. The main advantages of this natural material are that it is easy to be obtained, cheaper, and biodegradable, so it does not cause environmental problems [1],[2]. Coconut fiber has the highest tensile strength among all-natural fibers because it contains 54% cellulose [3]. The fiber has a high lignin content so that the degradation process is the slowest among other natural fibers. The fiber can last between 4 and 10 years [4]. Coconut fiber has a higher coefficient of friction and is more elastic compared to synthetic fibers [5][6],[7]. According to Oroh et al. [8], the fibers in coconut coir have mechanical properties that are rigid, tough, and resistant to compressive forces to withstand cracks and fractures. The strength of the fiber itself varies, depending on the size of the diameter and the degree of defects that exist in the fiber. If they are mixed thoroughly, these fibers will work optimally throughout the soil layer [9].

Soil reinforced using randomly distributed fibers behaves as a composite material, which is then known as the eco-composite [4]. This behavior is like the roots of plants that contribute to the strength of the soil. Fibers with sufficiently high tensile strength will help soil that only has compressive strength [4]. There have been many studies on the effect of fiber inclusions randomly in the soil. The effect of fiber orientation, which includes random, horizontal, and vertical, is proven not to affect the Unconfined Compression Strength (UCS) value of sand soil [10].

Himanshu et al. [11] conducted CBR and UCS tests on low plasticity clay (CL) mixed with coir fiber. The value of UCS increases with increasing fiber. The maximum increase occurred in soil mixed with fiber as much as 0.75%. The same results were obtained from the UCS research conducted on highly compressible clay [12]. In Venkatesh et al.'s research, the maximum value was obtained at 1% fiber [13], while the Upadhyay and Singh study obtained the maximum value at 1.5% fiber [14]. Menezes et al. [15] conducted a UCS test on clayey sand soil. The highest UCS was obtained at the fiber content of 0.5%, namely 635.4 kPa or an increase of 50.78% of the soil original. Several studies conducted UCS tests from soil mixed with coir fiber and other materials, including lime [16], using a mixture of bentonite, lime, gypsum [17], rice husk ash [6],[18],[19], fly ash [20], lime and coir fiber ash [16], carbon tetrachloride & sodium hydroxide [21], polypropylene fiber [22], basalt fiber [23], organic polymers and sisal fiber [24]. Widianti et al. [25] have studied direct shear strength on clay strengthened with coconut fiber. The maximum shear strength is generated at fiber content of 0.75%.

This study was carried out to add coconut fiber waste to the UCS of clay and obtain the optimum fiber content to produce UCS's maximum value.

2. RESEARCH METHODOLOGY

2.1. Soil

Soil samples were collected from Kulon Progo, Yogyakarta, Indonesia (Fig. 1). Widianti et al. [25] have tested the soil's engineering properties in previous studies, as shown in Table 1. Table 1 shows that the clay which was used is high plasticity clay. Therefore, it has a low bearing capacity.

Fig. 1. Clay soil

Table I. The Engineering Properties of the Soil Samples [25]

Parameters	Values	Method Standard
Specific Gravity, Gs	2.63	ASTM D854–10
Particle sizes distribution: Sand (%) Silt (%) Clay (%)	 13.36 70.58 16.06	ASTM D422-63 ASTM D6913-04
Consistency limits: Liquid Limit, LL (%) Plastic Limit, PL (%) Shrinkage Limit, PL (%) Plasticity Index, PI (%)	 89.91 38.86 16.33 51.05	ASTM D4318–10
Proctor standard compaction: Maximum Dry Density, MDD (kN/m^3) Optimum Moisture Content, OMC (%)	 12.64 29.90	ASTM D698-12
Soil Classification (USCS)	CH (inorganic clays of high plasticity, fat clays)	ASTM D2487-11
Soil Classification (AASHTO)	A-7-6 (clayey soils)	ASTM D3282-09
Activity	3,18 (> 1.25, active clays/montmorilonite)	

2.2. Coconut Fibers

Coconut fibers were mostly obtained from waste in the traditional market (Fig. 2). The fiber's tensile strength showed in Table 2. It can be concluded that coconut fiber has high tensile strength, so it is expected that the fiber can increase the soil's bearing capacity.

Fig. 2. Coconut Fibers

Table II. The Tensile Strength of the Coconut Fibers

Sample number	Diameter (mm)	Length (mm)	S□□□□□ □(%)	Tensile strength (MPa)
1	0.0272	100	30.97	225.0
2	0.0313	100	20.53	240.8
3	0.0411	100	34.10	147.2
4	0.319	100	27.80	107.4
5	0.208	100	32.60	121.6
		Average	29,20	168.4

2.3. Mix Design

The fibers were cut into small pieces, from 30 to 50 mm in length, and then were randomly mixed into the soil until it is homogeneous. The coconut fiber content variations used were 0.25%, 0.5%, 0.75% and 1.0% of the mixture's weight under the conditions of optimum moisture content (OMC) and maximum dry density (MDD). Two specimens were made for each mixture.

2.4. Testing Procedure

The primary test in this study is the unconfined compression test referring to ASTM D2166-16 [26]. The specimens have a height of 68 mm and a diameter of 35 mm (Fig.3).

(a) The specimen, when tested (b) The specimens after testing

Fig. 3. The specimens

3. RESULT AND ANALYSIS

3.1. Effect of Coconut Fiber on Unconfined Compressive Strength

According to ASTM [26], the Unconfined Compressive Strength (UCS) is the maximum axial stress value withheld by the cylindrical specimen before collapsing or experiencing 15% axial strain. The UCS test results of the soil strengthened with varied coconut fiber content can be seen in Fig. 4.

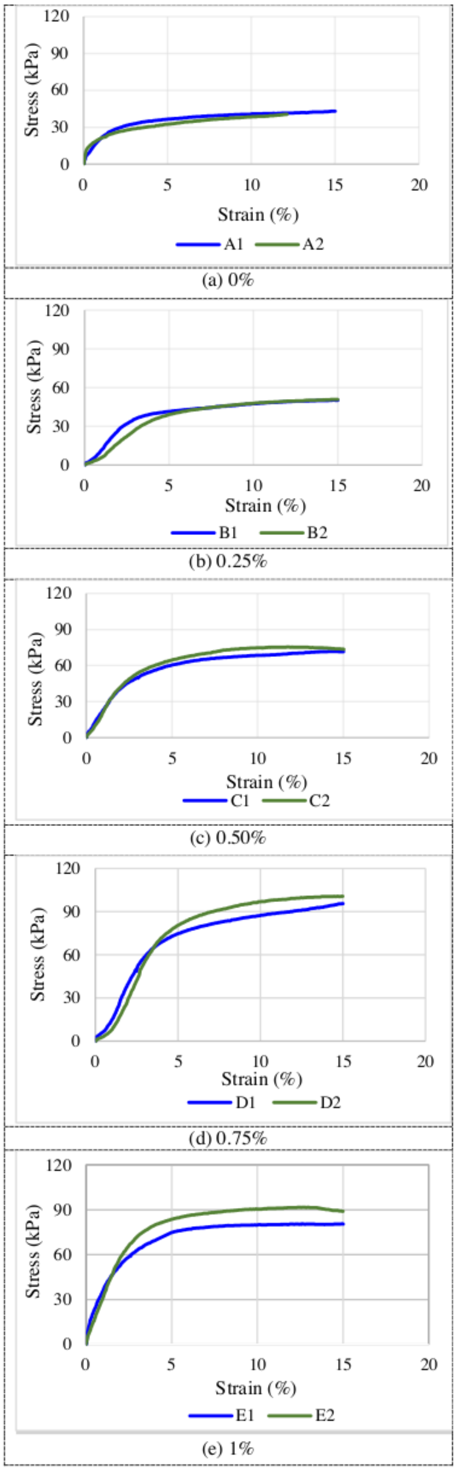

Fig. 4. The relationship between axial strain and soil stress with varying fiber content

Based on Fig. 4, each mixture's UCS value can be determined, as shown in Fig. 5.

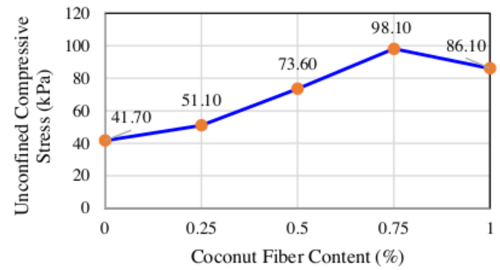

Fig. 5. The clay's UCS is strengthened by varied fiber content

Fig. 5 shows that reinforcement with coconut fibers can increase the UCS value of the soil. Before mixing with fiber, the UCS value in clay was 41.70 kPa. This value enhances the enhancing amount of coconut fiber. The maximum UCS value has occurred at the fiber content of 0.75%, which was 135.25%. These results are the same as research conducted by Himanshu et al. [11] and Sujatha et al. [12], which says that the optimum fiber content is 0.75%. According to Menezes et al. [15], the soil becomes active when subjected to external loads. This behavior will increase the interaction between soil and fiber so that the strength of the composite increases. However, the fiber that exceeds the optimum amount will reduce its strength because the fibers will interact with each other, not with the soil.

Based on the UCS value, clay soil consistency can be classified [27]. Initially, clay, which has a UCS value of 41.70 kPa, is classified as soft soil. With the addition of coconut fiber, the mixture is classified as stiff clay.

3.2. Effect of Coconut Fiber on Secant Modulus (E_{50})

Secant modulus is the value of stress resistance at 50% before the test object deforms. Based on the UCS value and Fig. 4, the secant modulus value can be calculated (Fig. 6).

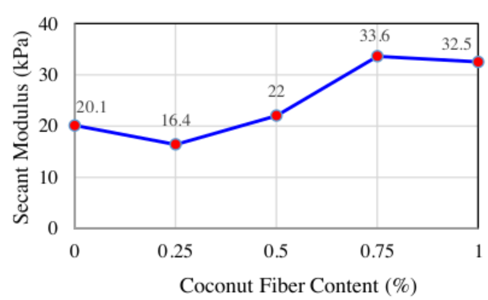

Fig. 6. The clay's secant modulus is strengthened by varied fiber content

Fig. 6 shows the secant modulus ($\square_{50}$) increase with increasing fiber content. This increasing value of E_{50} shows that the mixture is getting stiffer [28]. The results showed that the secant modulus increased from 20.10 kPa to 33.60 kPa in 0.75% coconut fiber mixture, increased by 153% compared to the sample without added fiber. However, if the fiber content is more than 0.75%, the secant modulus will decrease. One of the factors affecting the secant modulus is the bond between soil grains. If there are too many fibers, the bonds between grains are reduced.

4. CONCLUSION

1. The value of the unconfined compressive strength of clay has increased along with the more coconut fiber added.

2. The maximum value of unconfined compressive strength and secant modulus obtained in clay with coconut fiber reinforcement is 0.75% of the mixed soil weight.

3. The clay strengthened with coconut fiber becomes stiffer than the initial soft clay, thereby improving its soil stability.

In further research, it is necessary to test the durability of a mixture of soil and coconut fiber. In further research, it is necessary to test the durability of a mixture of soil and coconut fiber.

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