UTILIZATION OF COIR FIBERS TO IMPROVE THE BEARING CAPACITY AND TENSILE STRENGTH OF EXPANSIVE CLAY

by Anita Widianti, Angesta Artha Bhakti Negara , Tjokro Seigia

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UTILIZATION OF COIR FIBERS TO IMPROVE THE BEARING CAPACITY AND TENSILE STRENGTH OF EXPANSIVE CLAY

*Anita Widianti[1], Angesta Artha Bhakti Negara[2], Tjokro Seigia Elmino[3] and Lazuardi Ramadhani[4]

[1,2,3,4]Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia

*Corresponding Author, Received: 10 Nov 2021, Revised: 17 April. 2022, Accepted: 28 May 2022

ABSTRACT: Reinforcement is a method to improve soils with low bearing capacity and tensile strength. Coconut coir waste is an alternative reinforcement material because coir fibers have high tensile strength, high shear strength, and high resistance to compressive stress. This study performed the soaked and unsoaked California Bearing Ratio (CBR), the swelling, and the indirect tensile strength tests focusing on expansive clay reinforced with coir fibers. The content of coir fibers was between 0.00% to 1.25% by weight of the mixture. The fibers were cut into 30 mm to 50 mm long pieces, then mixed randomly into the soil in various content. The mixture was compacted based on the maximum dry density and the optimum moisture content of the clay. The test results revealed that the soaked and unsoaked CBR reached the maximum values at 1% fiber content. Originally of poor quality, the soil condition became quite good after being reinforced with an optimum fiber content of 1%. All specimens swelled when soaked. The swelling values tended to increase with the addition of coir fibers. Hence, the expansive clay must be chemically stabilized to reduce swelling. The tensile strength reached the maximum value at 0.6% fiber content.

Keywords: Expansive clay, Coir fiber, California Bearing Ratio, Swelling, Tensile strength

1. INTRODUCTION

Expansive clay is soil causing numerous problems in construction due to its low bearing capacity, high plasticity index, and high shrink-swell behavior influenced by its water content [1-2]. Low bearing capacity can result in the collapse of the foundation or slope failure. There have been many methods of soil improvement to enhance the physical and mechanical properties of clay. One of them is by providing soil reinforcement by inserting material into the soil to increase stability and reduce compressibility and lateral deformation [3]. One of the materials used is fiber mixed randomly into the soil. Soil and fiber will behave as a composite material called eco-composite [4]. This behavior is like plant roots that contribute to improving the strength of the soil. Fibers with relatively high tensile strength will help soils that cannot withstand tensile force [5]. Muntohar et al. [6] explained that the reinforcement works from low to peak strain. After the peak strain has passed, the reinforcement can still provide tensile stress to prevent sudden failure. The principle of strengthening soil using fibers is the adhesion between the fibers and the soil grains. This condition increases shear strength and bearing capacity while compressibility and lateral deformation decrease. Adding fibers can change the soil from brittle to ductile [7]

Reinforcement can use various kinds of fiber, one of which is coconut fibers. Although the fibers are biodegradable, they have high durability and strength [8]. The fibers' strength varies depending on the fiber's length, diameter, and degree of the defect [9-10].

Carrijo et al. [11] asserted that 35% of the total weight of coconut is coir, consisting of 75% fibers and 25% pitch. Coir fibers contain 54% cellulose and 46% lignin [11-12]. Due to the high lignin content, the degradation of coir occurs more slowly than other natural fibers. The age of coir can reach ten years [13]. Coir fibers can maintain their tensile strength when wet and have high stretch. Compared to synthetic fibers, coir fibers are more elastic and have a higher coefficient of friction [13-14]. Coir fibers also offer other advantages: lightweight, resistant to microbial decomposition, resistant to fungi, environmentally friendly [11-12], and abundant at low prices in many Asian countries [15-16]. Indonesia is the largest coconut producer based on 2019 Food and Agriculture Organization (FAO) data. Coconut production in Indonesia reached 17.13 million tons/year in 2019 [17].

Structural materials still rarely apply coir waste. So far, coir fibers have been utilized for fuel, household appliances, handicraft materials, simple water filters, environmentally friendly briquettes, and planting media [8]. As a construction material, coir fibers become an alternative to reduce coir fiber waste and are expected to help overcome environmental problems [18].

The California Bearing Ratio (CBR) is a parameter to indicate the bearing capacity of the subgrade. Research on the effect of coir fiber content on the CBR value of soil has been carried out and revealed to increase soil bearing capacity. Fiber is mixed into the soil randomly. The optimum amount of fiber content to produce the maximum CBR value has disclosed various results, between 0.5% to 1.5% [19-23]. According to Nyuin et al. [18], there is no clear relationship between coir fiber orientation and the shear strength of the soil.

Research on CBR, swelling and tensile strength focusing on expansive clay reinforced with coir fibers has not been widely conducted. Shukla et al. [24] performed soaked and unsoaked CBR tests on expansive clay mixed with coir fibers. The test results discovered that the CBR values increased with the increase in fiber content. The maximum CBR value was 1% mixture. Munirwan et al. [1] also conducted CBR research on expansive soil reinforced with 20 mm and 30 mm fibers. Mixing was performed randomly and in layers. Random mixing with a fiber length of 30 mm and a fiber content of 0.4% resulted in the highest CBR value.

As Anggraini et al. [25] discovered, coir fibers could significantly increase the tensile strength of clay. Fibers could improve friction in the soil. The optimum fiber content for the soil mixture was 1%. Menezes et al. [26] analyzed the mechanical behavior of clay-sand soil by adding coir fibers. The highest tensile strength value was soil with 0.75% coir fiber reinforcement. The addition of fibers also generated a more ductile soil-fiber mixture.

In this study, laboratory tests on soaked and unsoaked CBR, swelling, and tensile strength of expansive clay mixed with coir fibers aimed to determine the effectiveness of the fibers as soil reinforcement.

2. METHODOLOGY

2.1 Materials

This study deployed expansive clay soil from Sentolo, Kulon Progo, Yogyakarta, Indonesia. Widianti et al. [27] tested the physical properties of the soil, obtaining specific gravity (Gs) = 2.64, liquid limit (LL) = 89.91%, plastic limit (PL) = 38.86%, shrinkage limit (SL) = 16.33% and plasticity index (PI) = 51.05%. The soil contained 86.64% fine grains and 13.36% coarse grains. Following the classification of AASHTO, it belongs to clayey soil, indicated as a poor subgrade material (A-7-6). Based on the USCS classification, it is classified as clay with high plasticity (CH). According to Skempton, the value of soil activity is 3.18, signifying active clay (containing the Montmorillonite mineral). The standard proctor compaction test disclosed the Maximum Dry Density (MDD) = 12.8 kN/m^3 and the Optimum Moisture Content (OMC) = 29.9%. All parameters were obtained from laboratory testing based on ASTM standards.

Coir waste is abundantly available in the markets. Table 1 exhibits the average diameter and fiber tensile strength values.

Table 1 The tensile strength of coir fibers

Sample	Length (mm)	Average diameter (mm)	Tensile strength (MPa)
1	100	0.15	92.20
2	100	0.21	110.36
3	100	0.21	121.86
4	100	0.23	143.39
5	100	0.23	147.20
6	100	0.32	107.41
	Average tensile strength		120.40

2.2 Variation of Specimens

This study performed the soaked and unsoaked CBR and indirect tensile strength tests of expansive clay mixed with coir fiber content. Tables 2 and 3 display the variation and number of the specimens.

Table 2 Variation and number of CBR specimens

Sample Number	Mixed Variation		Number of Specimens	
			Soaked CBR	Unsoaked CBR
1	Without fiber reinforcement		2	2
2	With fiber reinforcement	0.25%	2	2
3		0.50%	2	2
4		0.75%	2	2
5		1.00%	2	2
6		1.25%	2	2

2.3 Preparation of Specimens

The fibers were cut into pieces with lengths of 30 mm to 50 mm, then mixed randomly (ignoring the fiber orientation) into the soil in various content. The mixture was compacted according to proctor standards. MDD and OMC values of clay became a reference in the compaction process.

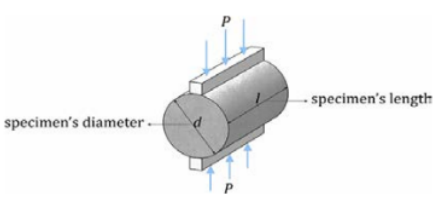
Table 3. Variation and number of indirect tensile strength specimens

Sample Number	Mixed Variation		Number of Specimens
1	Without fiber reinforcement		2
2	With fiber reinforcement	0.40%	2
3		0.60%	2
4		0.80%	2
5		1.00%	2

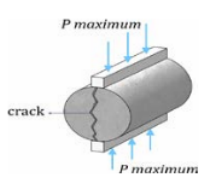
2.4 Testing Procedure

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 values). The CBR tests were carried out based on ASTM D1883-07e2. Static load continued to be applied gradually to the specimens until the displacement value was 12.7 mm (0.5 inches).

The indirect tensile strength specimens were cylinders with a 3.5 cm diameter and a 7 cm length. The tests utilized an unconfined compressive strength machine based on ASTM C-496. Static load continued to be applied gradually at a constant rate (0.96 MPa/min) until the occurrence of cracks that marked the failure of the specimens, as displayed in Fig. 1.



(a)



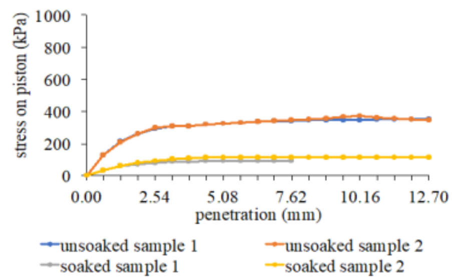
(b)

Fig. 1 Schematic diagram of indirect tensile strength test (a) during loading, (b) at failure

3. RESULTS AND DISCUSSION

3.1 The CBR Values of Coir Fiber-Reinforced Expansive Clay

The relationship between penetration and stress on the piston for the expansive soil reinforced with various coir fiber content is portrayed in Fig. 2.



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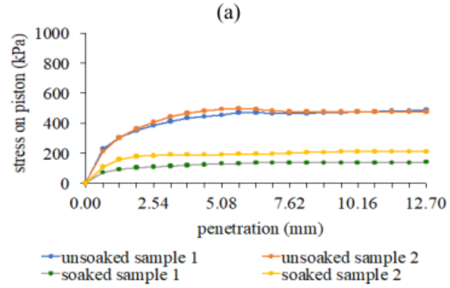

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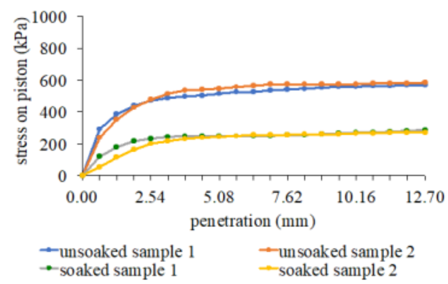

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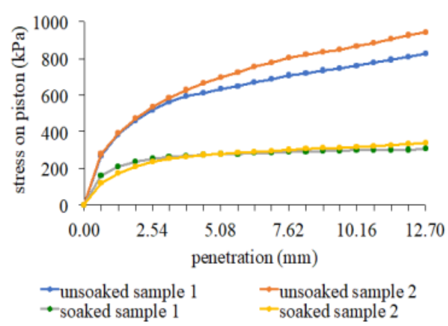
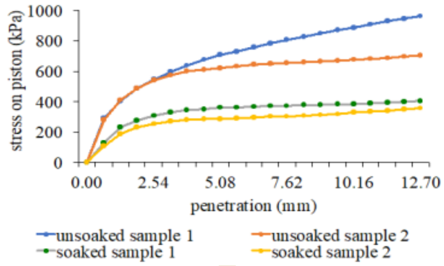
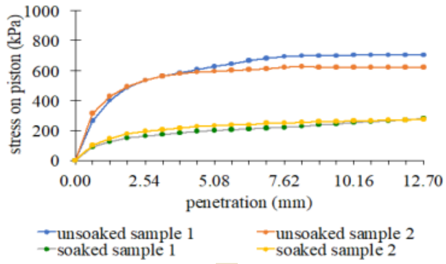


(d)



(e)



(f)

Fig. 2 Relationship between penetration and stress on the piston (a) 0%, (b) 0.25%, (c) 0.5%, (d) 0.75%, (e) 1.0% and (f) 1.25%

Based on Fig. 2, the CBR values were determined, as depicted in Fig. 3.

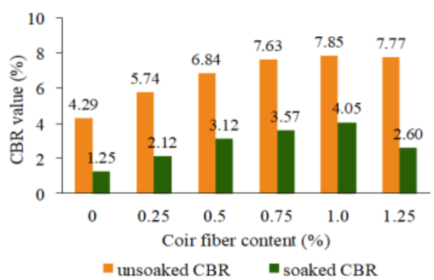


Fig. 3 Relationship between coir fiber content and CBR values

The soaked and unsoaked CBR values increased along with the increasing coir fiber content mixed into the soil. Soil with 1% fiber content produced a maximum CBR value. At this content, the unsoaked CBR values increased from 4.29% to 7.85% (an increase of 83% from the expansive clay CBR values), while the soaked CBR values increased from 1.25% to 4.05% (an increase of 224% from the clay CBR values). At the level of 1.25%, the CBR values began to decline. These results are similar to those conducted by Singh and Mittal [7], Lekha, et al. [28], and Shukla et al. [24].

Hejazi et al. [4] disclosed that coir fibers had a good resistance response and high friction coefficient. The fibers randomly mixed into the soil in a certain amount increased the friction between the soil particles and the fiber surface. The soil's shear strength increased, increasing its bearing capacity [14,16]. Shukla et al. [24] revealed that the soil-fiber mixture increased the bonding or interlocking between the two. Soil grains cannot withstand horizontal force. The fibers will help resist their tensile strength when the soil grains move horizontally. At higher than optimal fiber content, the CBR values will decrease. The fibers will interact with each other. The amount of soil grain available is not enough to create a strong bond between the soil and the fibers [25-26].

The CBR values can demonstrate the quality of the soil, as described in Table 4. Clay soil with an unsoaked CBR value of 4.29% has poor quality. After being reinforced with an optimum fiber content of 1%, the CBR value was 7.85%, thus increasing the soil quality to fair.

Table 4. Pavement quality rating [29]

CBR (%)	General Rating
> 50	Excellent
20-50	Good
7-20	Fair
3-7	Poor
0-3	Very poor

3.2 The Swelling Values of Coir Fiber-Reinforced Expansive Clay

The compaction of the CBR specimens was carried out by controlling the water content of the clay at the optimum moisture content, which was 29.9%. The water content increased after the specimens were soaked for four days and after being mixed with fibers (Fig. 4). This increase was accompanied by an increase in swelling (Fig. 5).

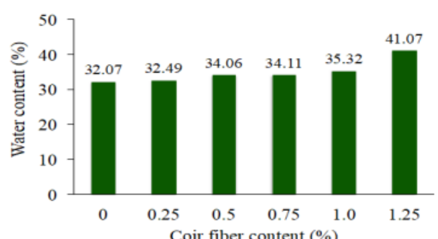


Fig. 4 Relationship between coir fiber content and water content after soaked for four days

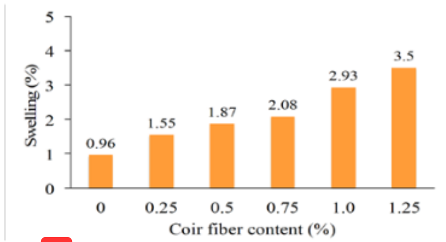
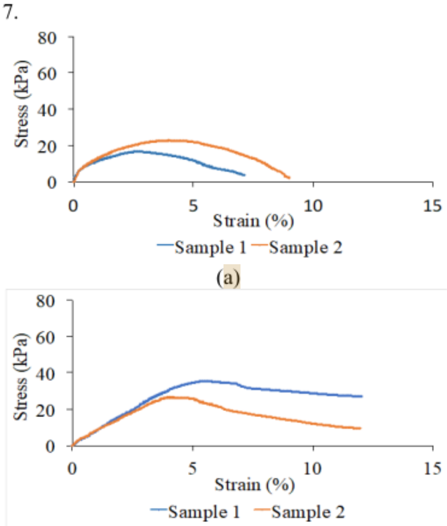


Fig. 5 Relationship between coir fiber content and swelling

Water content has become one of the factors causing soil swelling. The tension in the water between the soil particles tended to push the soil particles away from each other, resulting in swelling. The existing fibers were unable to withstand the expansion. The more coir fibers added, the higher the swelling value obtained. The average swelling value for the soil without fiber was 0.96%. It increased to 3.50% for the mixture with 1.25% fiber content. Therefore, the expansive clay must be chemically stabilized to reduce swelling. Soil grains will undergo a chemical reaction with the added material, resulting in the flocculation of soil particles. These enlarged grains will minimize swelling [30].

3.3 The Tensile Strength Values of Coir Fiber-Reinforced Expansive Clay

The results of tensile strength testing for each variation in the laboratory are shown in Fig 6. All the specimens mixed with the fiber become ductile and have greater strain. Based on Fig 6, the tensile strength value can be determined, as shown in Fig. 7.



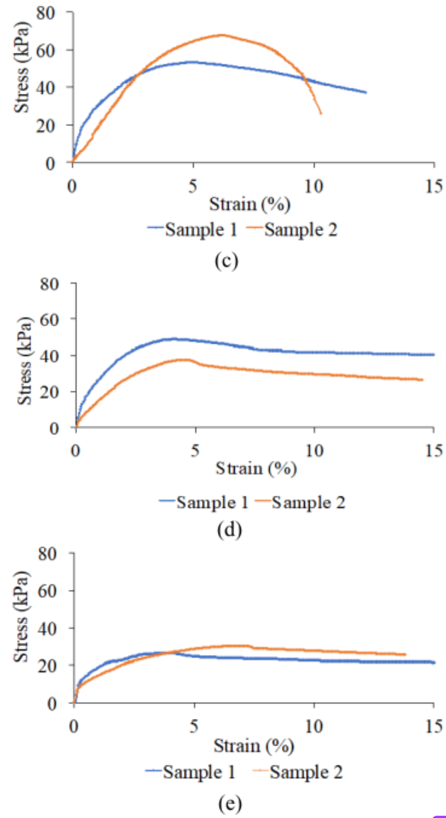


Fig. 6 Relationship between strain and stress (a) 0%, (b) 0.4%, (c) 0.6%, (d) 0.8% and (e) 1.0%

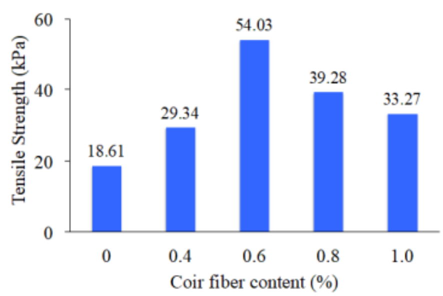
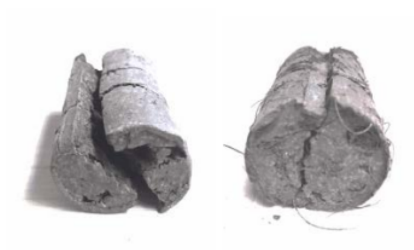


Fig. 7 Relationship between coir fiber content and tensile strength

The tensile strength value of the specimen without coir fibers was 18.61 kPa. The tensile strength value tended to increase with increasing fiber content. The tensile strength reached the highest value of 54.03 kPa with 0.6% fiber content (there was an increase of 190% from the tensile strength of clay). It was the optimum fiber content to achieve maximum tensile strength. If it exceeds the optimum level, the effectiveness of the interaction between the fibers and the soil will decrease. The fibers' interlocking with soil will reduce because those fibers interact [26].

Fig. 8 exhibits specimens after testing. Lateral deformation and rupture occurred along the stress plane in unreinforced soil (Fig. 8a). However, with fiber reinforcement, soil stiffness increased. The soil only cracked along the stress plane (Fig. 8b).



(a) (b)

Fig. 8 The indirect tensile strength specimens after testing (a) without fiber content and (b) with 1.0% fiber content

4. CONCLUSION

The addition of coir fibers as soil reinforcement mixed randomly (ignoring the fiber orientation) could significantly increase the soaked CBR, the unsoaked CBR, and the tensile strength of the soil. The soaked and unsoaked CBR reached its maximum value at 1.0% fiber content, while the indirect tensile strength reached its maximum value at 0.6% fiber content.

The swelling values tended to increase with the addition of coir fibers. Expansive clay must be chemically stabilized to reduce swelling.

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