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Submission date: 10-Apr-2023 07:49AM (UTC+0700)
Submission ID: 2059943691
File name: 4._UKARST-_geser_langsung.pdf (583.22K)
Word count: 4347
Character count: 20865

Ukarst : Universitas Kadiri Riset Teknik Sipil.
Volume 4 Number 2, (2020).
ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

Available online at
http://ojs.unik-kediri.ac.id/index.php/ukarst/index
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http://dx.doi.org/10.30737/ukarst.v3i2

Direct Shear Strength Of Clay Reinforced With Coir Fiber

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ARTICLE INFO

Article History :
Article entry : 17-08-2020
Article revised : 05-09-2020
Article received : 17-09-2020

Keywords :
Shear Strength, Direct Shear Strength Test, Clay, Coir Fiber, Reinforcement.

IEEE Style in citing this article :
[3] A. S. Muntohar, A. Widianti, E. Hartono, and W. Diana, "Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber," J. Mater. Civ. Eng., vol. 25, no. 9, 2013.

ABSTRACT

Indonesia is the largest coconut producing country in the world. However, the resulting coir waste is still rarely used for structural materials. This research studied the effect of random inclusion of coir fiber on the shear strength of clay with high plasticity. The carried test in this study is a direct shear strength test. The fiber content variations used are 0%, 0.25%, 0.50%, 0.75%, and 1% of the dry weight of the mixture with a fiber length of between 30 mm to 50 mm. The results show that the reinforcement of coir fiber can increase the cohesion and friction angle. The maximum increase in cohesion value was obtained at fiber content of 0.75%, which was 39.66%. The increase in the value of the friction angle was obtained at 1% fiber content, which was 46.67%. The optimum coir fiber content was achieved at the fiber content of 0.75%. With this content, the value of the shear strength reaches its maximum with an increase of 39.4% at a normal stress of 8.071 kPa.

1. Introduction

Soil bearing capacity is the soil's ability to support the load of the foundation of the structure on it. The bearing capacity states the shear resistance of the soil to resist settlement due to loading [1]. Efforts to increase the low bearing capacity can be done in various ways. One way is to reinforce in the form of short fibers which are mixed randomly into the soil. These materials will interact with the soil through adhesion, so that the shear strength and tensile strength of the soil increase, and the soil becomes more ductile [2],[3].

Soil reinforcement by utilizing coir waste is a usable alternative because this natural material is cheap/economical, light, environmentally friendly [4],[5], and is native to the tropics so it is easily found throughout Indonesia [6]. According to data from the Food and Agriculture Organization (FAO) in 2019, Indonesia is the largest coconut producer in the world. In 2018 the production reached 18.55 million tons/year [7]. However, the produced

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coir wastes are unfortunately still rarely used as structural materials. Many researches have been carried out, but they provide various results and recommendations. In this research, a study will be conducted on the contribution of coir fiber to the shear strength of clay with high plasticity so that the proportion of coir fiber waste which produces the maximum shear strength will be obtained.

2. Literature Review

Coconut consists of coir (35%), shell (12%), fruit juice (25%), and fruit flesh (28%) [6]. Each coconut coir consists of 75% coarse fibers and 25% cork that connects one fiber to another. Coir fibers have a length of about 60-250 mm, a diameter of about 0.1-0.45 mm, a tensile strength of about 15-327 MPa, elongation of about 10-75% [8], and consist mostly of lignin and cellulose. Due to the high lignin content, coir fibers are resistant to microbial breakdown and are resistant to salinity. Therefore, degradation of the fibers occurs slower than other natural fibers and can be up to 10 years. Due to the coir's high cellulose content, it can maintain its tensile strength when it is wet and has high tensile strength. Compared to synthetic fibers, coir fibers are more elastic and have a higher coefficient of friction [9].

Researches on the use of coconut coir fibers to increase the shear strength of the soil using the direct shear strength test have been carried out by several previous researchers. Kar, et al. conducted research on cohesive soil which was randomly mixed with coir fiber, with a fiber length of 20 mm. The highest shear strength was achieved at fiber content of 0.8% with an increase in the cohesion value of 2.7 times, and an increase in the friction angle of 1.5 times [10]. Subramani and Udayakumar used coir fiber with a diameter of 0.5 mm, a length of 30 mm and 50 mm as a reinforcement for soft clay. The test showed that 0.5% fiber content resulted in an optimum increase [11]. Suffri, et al. stated that coir fiber can increase the shear strength of soft clay with moderate plasticity in Brunei Darussalam [12]. Research Upadhyay and Singh showed an increase in shear strength with an increase in cohesion value by 34.7% and an increase friction angle by 0.8% in the fiber content of 0.5% coir fiber [13]. Gupta et al. conducted a study using coir fibers with a fiber length of 20 mm and 40 mm, and it was shown to increase 3.9% to 8.6% in the fiber content of 1% [14]. Tiwari and Mahiyar studied expansive soils mixed with coir fiber, ash, and glass pieces. The results of this study indicated that the addition of these materials can increase the value of friction angle and soil permeability, while the value of cohesion decreases [15]. In the research of Khatri et al., the coir fiber was treated with a solution of sodium hydroxide and carbon tetrachloride before being mixed into the soil. The results showed that the peak stress, cohesion, and friction angle

http://dx.doi.org/10.30737/ukarst.v3i2 .

ISSN (*Online*) 2581-0855
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increased, thereby increasing the shear strength of the soil [16]. In the study of Sarvade, et al. the researchers used clay from South India. In this study, the soil was reinforced with coir which was shaped like a mat, at different positions, where the coir mat was covered with cashew nut oil. The soil which was covered with coir mats experienced a 3 times increase in bearing capacity than the non-reinforced soil, the compressive strength increased by 88%, while cohesion increased by 5 times that of non-reinforced soil [17].

Das, et al. conducted a direct shear strength test on sandy soil. The results showed that the sandy soil which was reinforced with coir fiber with a length of 15 mm experienced an increase in shear strength by 21.5% [18]. Lastiko and Sulistyorini tested the stability of poorly graded sandy soils using coir fibers that were cut to between 30mm to 50mm long. The test results showed that the addition of coir fiber can increase the shear strength by 10.30% for the coir fiber content of 1.5% [19]. Suryadharma and Hatmoko conducted a study on the shear behavior of sand and clay stabilized with lime, rice husk ash, and coir fiber. The fiber content was fixed at 1.2% of the dry weight of the soil. With the addition of fibers, the cohesion value decreases, and the friction angle increases [20].

Fahriani and Apriyanti analyzed the bearing capacity of shallow foundations in the form of squares and rectangles using the Terzaghi method on the original soil and soil which had been added with coir fiber. The optimum coir fiber content of 1% has resulted in the largest increase in foundation bearing capacity. The use of coir fiber to increase the bearing capacity of the foundation is recommended not more than 2% of the dry weight of the soil [21].

3. Research Method

3.1. Preliminary Test.

The clay soil was taken from Sentolo, Kulon Progo, Yogyakarta. They were dried and crushed into small pieces in the laboratory and sieved by passing through a 4.75 mm sieve. The properties of the soil samples are shown in **Table 1** and **Figure 1**.

Coir fibers were collected from waste from traditional markets. The fibers were dried, separated from the cork and cut into lengths of between 30 to 50 mm. Then, the fiber tensile test was carried out to find out how much tensile strength the fibers had. The results of the tensile strength test are shown in **Figure 2**. Based on this figure, the average tensile strength of the coir fibers is 126.11 MPa.

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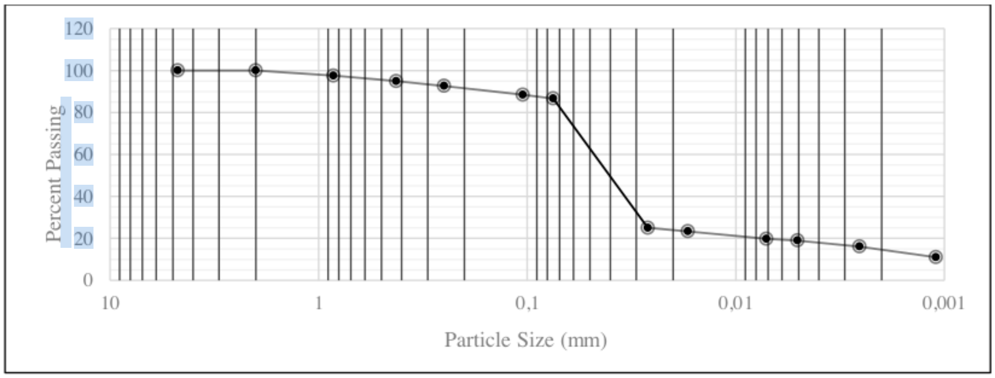
Table 1. Properties of the Soil Samples

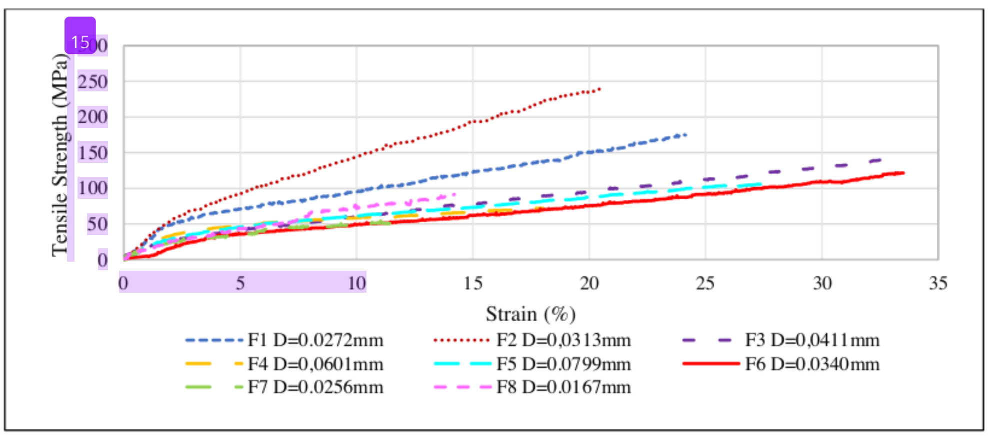
No	Parameter	Result
1	Specific Gravity, G_s	2.63
2	Sand Fraction	13.36%
3	Silt Fraction	70.58%
4	Clay Fraction	16.06%
5	Liquid Limit, LL	89.91%
6	Plastic Limit, PL	38.86%
7	Plasticity Index, PI	51.05%
8	Shrinkage Limit,SL	16.22%
9	Maximum Dry Density, MDD	12.64kN/m^3
10	Optimum Moisture Content, OMC	29.90 %
11	Classification according to USCS	CH (Inorganic clay with high plasticity)

Source : Result of This Study.



Source : Result of This Study.

Figure 1. Particle-Size Distribution Curve.



Source : Result of This Study.

Figure 2. Tensile Stength of The Coir Fibers.

http://dx.doi.org/10.30737/ukarst.v3i2 .

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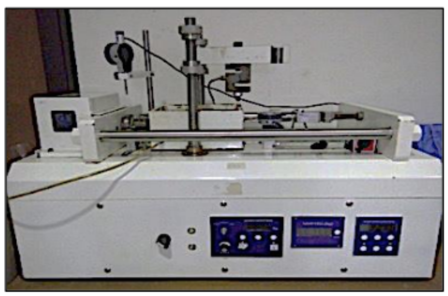
ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

3.2. Specimen Preparation.

All specimens were made by using a cylindrical mold with a diameter of 6.22 cm and a height of 2.11 cm. The specimens were molded under the conditions of maximum density and optimum moisture content. The percentage variations of the coir fibers were decided as 0%, 0.25%, 0.5%, 0.75%, and 1% of the dry weight of the mixture. The fibers were mixed randomly into the clay until they were evenly distributed. Each variation of fiber content was made as many as 3 specimens for 3 variations of the load test, which were 2.5 kg (8.07 kPa), 5 kg (16.14 kPa), and 10 kg (32.28 kPa).

3.3. Direct Shear Strength Test.

In this step, a direct shear strength test for each specimen was carried out with reference to the SNI (Indonesian National Standard) 3420:2016 [22]. The direct shear strength test apparatus can be seen in **Figure 3**, while one of the specimens is shown in **Figure 4**.



Source : Geotechnical Laboratory, UMY.

(a) Direct Shear Strength Test (Electronic).

Source : Geotechnical Laboratory, UMY.

(b) Shear Box.

Figure 3. The Direct Shear Strength Test Apparatus.

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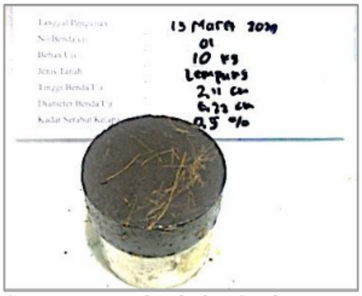
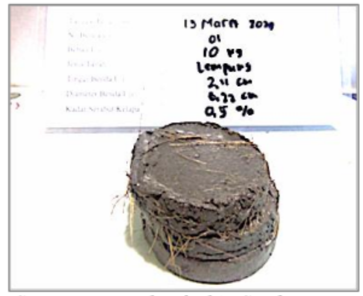
ISSN (Online) 2581-0855
ISSN (Print) 2579-4620



Source : Result of This Study.

(a) Before Testing.



Source : Result of This Study.

(b) After Testing.

Figure 4. Specimen with 0.5% Fiber Content.

4. Results and Discussions

4.1. Effect of Coir Fibers Content on Cohesion and Friction Angle.

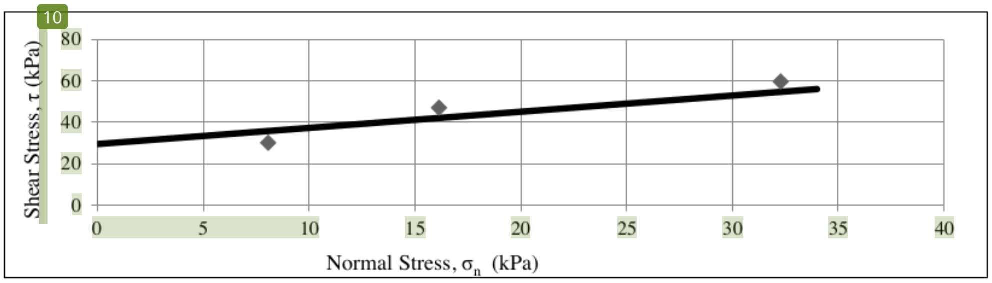
From the direct shear strength test, the normal stress and the maximum shear stress is obtained as shown in **Table 2**.

Table 2. Normal Stress and Maximum Shear Stress.

Normal Load (Kg)	Normal Stress (kPa)	Maximum Shear Stress (kPa) for Variations in Coir Fiber Content				
		0%	0.25%	0.50%	0.75%	1%
2.5	8.071	30.154	34.383	32.284	52.946	37.934
5	16.142	53.044	47.458	54.884	54.883	59.403
10	32.285	63.116	54.658	56.659	72.640	66.183

Source : Result of This Study.

Based on Table 2, a graph showing the relationship between normal stress and maximum shear stress could be made to determine the cohesion value (c) and the friction angle (ϕ) as a parameter of soil shear strength. The graph is shown in **Figure 5**.



Source : Result of This Study.

(a) Fiber Content of 0%.

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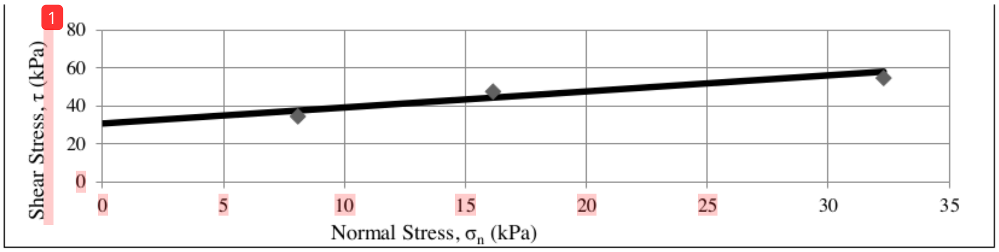
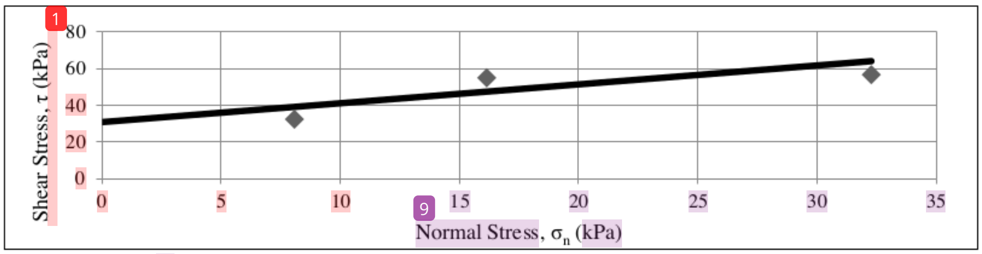
ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620



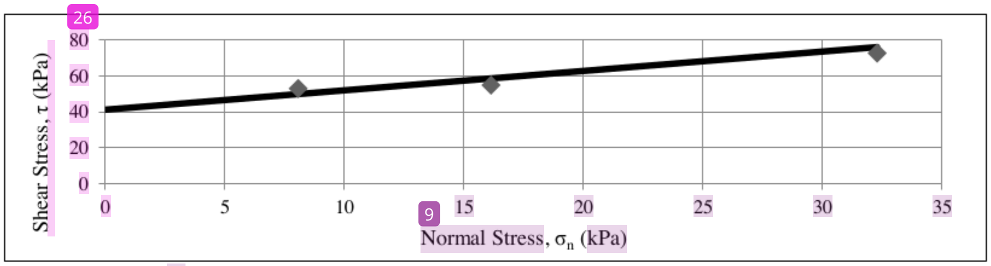
Source : Result of This Study.

(b) Fiber Content of 0.25%.



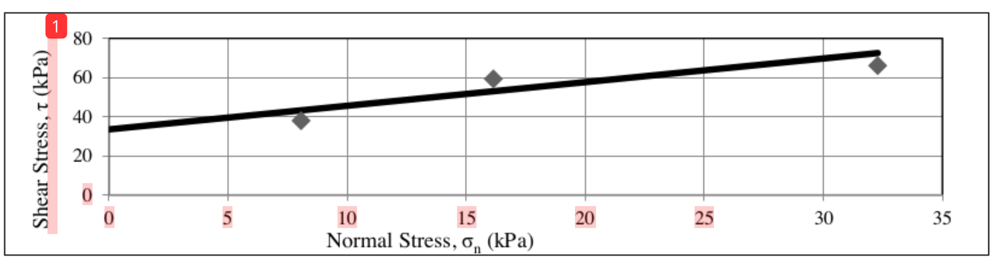
Source : Result of This Study.

(c) Fiber Content of 0.50%.



Source : Result of This Study.

(d) Fiber Content of 0.75%.



Source : Result of This Study.

(e) Fiber Content of 1%.

Figure 5. Relationship between Normal Stress and Maximum Shear Stress in Soil-Coir Fiber Reinforcement.

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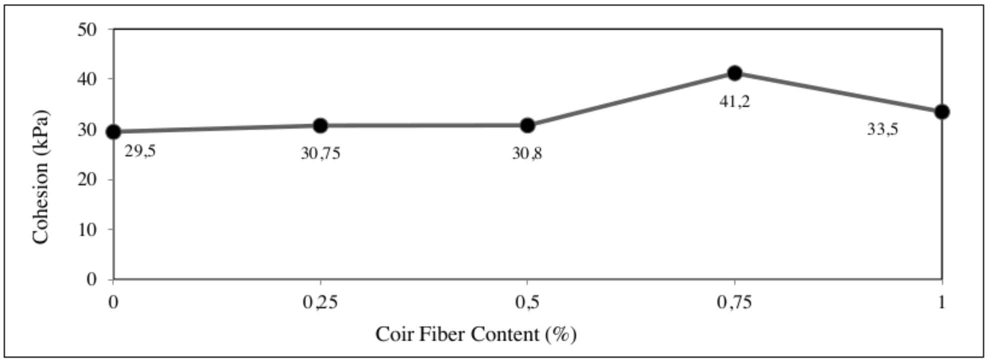
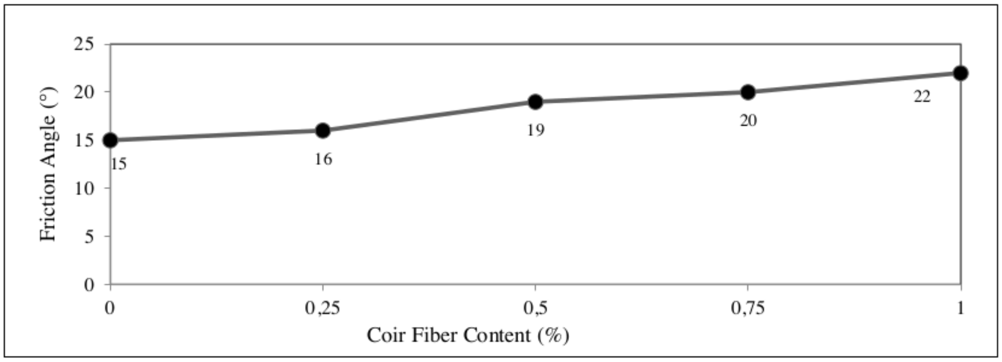
ISSN (*Print*) 2579-4620

Based on **Figure 5** which is a straight line, the cohesion value is obtained from the point on the y-axis which is cut by the straight line. The value of the friction angle is obtained from the angle of the straight line with the x-axis. The analysis results showing the cohesion value and internal shear angle are shown in **Figure 6** and **Figure 7.**



Source : Result of This Study.

Figure 6. Relationship between Coir Fiber Content and Cohesion.



Source : Result of This Study.

Figure 7. Relationship between Coir Fiber Content and Friction Angle.

Figure 6. and **Figure 7.** show that the soil reinforced with coir fibers can increase the cohesion (c) and the friction angle (ϕ). Initially, the soil had a cohesion of 29.5 kPa and an friction angle of 15°. After being reinforced by the coir fibers, the cohesion value had increased and reached the maximum value at the specimen with 0.75% coir fiber content, which was 41.2 kPa with a percentage increase of 39.66%. The value of the friction angle also increased along with the increase of coir fibers content which was mixed into the soil. The value of the friction angle reached its maximum at the coir fibers content of 1%, which was 22° with an increase of 46.67%.

http://dx.doi.org/10.30737/ukarst.v3i2 .

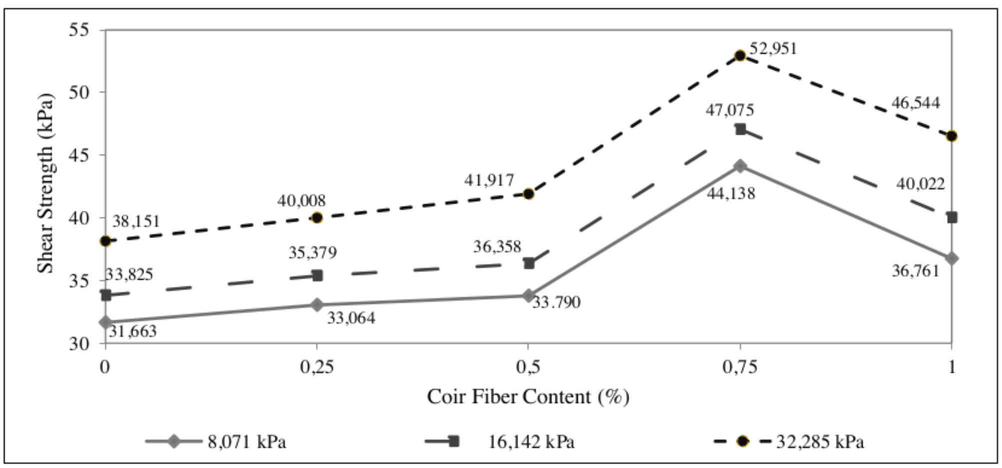
Ukarst : Universitas Kadiri Riset Teknik Sipil. ISSN (*Online*) 2581-0855
Volume 4 Number 2, (2020). ISSN (*Print*) 2579-4620

The cohesion value is determined by the magnitude of the tensile force among the soil grains. One aspect that affects the cohesion value is grain density. If the grain density is greater, the cohesion value which will be obtained is higher [23]. The addition of excessive coir fiber will cause the grain density to decrease and, therefore, the tensile forces between the grains of the soil will be reduced, resulting in decreased cohesion value.

Coir fibers that are randomly mixed into the soil will increase the contact surface area which increases the interaction between the fibers and the soil and also increase the interlocking between them, therefore, strengthens the soil in resisting shear forces [24],[25]. Any load received by the soil grain will be transferred to the fibers through the friction between the soil and the fibers. Fibers that have tensile strength will help withstand the tensile stress that is passed on to the soil by the friction. The value of the friction angle of the soil increases due to the help of the shear resistance provided by the coir fibers through the tensile strength of the fibers.

4.2. Effect of Coir Fibers Content on Shear Strength.

Soil shear strength is the resistance force exerted by the soil grains against tensile or compressive force. If the soil is subjected to loading, it will be born by the soil cohesion, which depends on the type of the soil and the soil density, as well as friction between the grains of the soil which is directly proportional to the vertical stress in the shear plane [26]. The value of shear strength of the clay which has been reinforced with coir fibers is presented in **Figure 8**.



Source : Result of This Study.

Figure 8. Relationship between Coir Fiber Content and Shear Strength.

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From **Figure 8**, it can be seen that the shear strength of clay soil reinforced by coir fibers with varying content has increased compared to clay soil without reinforcement. The maximum increase in the soil shear strength occurred at the fiber content of 0.75%, where the increase in normal stresses reached 39.4% at a normal stress of 8.07 kPa, whereas at a normal stress of 16.14 kPa the increase reached 39.17%, and at normal stresses of 32.28 kPa it reached 38.79%. According to Hejazi, et al., coir fibers which are distributed randomly to reinforce the soil will behave like plant roots which contribute to increasing soil strength. Soil that can not withstand tensile forces will be assisted by fibers that have relatively high tensile strength so that the shear strength increases to a certain limit of fiber content [9].

5. Conclusion and Suggestion

5.1. Conclusion.

Based on finding results as explained previous, there are some highlights that can be considered for conclusions as follows:

1. The addition of coir fiber to clay can increase the cohesion and the friction angle. The maximum increase in cohesion value was obtained at fiber content of 0.75%, which was 39.66%. The increase in the value of the friction angle was obtained at 1% fiber content, which was 46.67%.
2. The optimum coir fiber content was achieved at the fiber content of 0.75%. With this content, the value of the shear strength reaches its maximum with an increase of 39.4% at a normal stress of 8.071 kPa.

5.2. Suggestion.

Durability research needs to be done to determine the resistance of the mixture of soil and coir fiber to weather effects.

http://dx.doi.org/10.30737/ukarst.v3i2 .

Ukarst : Universitas Kadiri Riset Teknik Sipil. ISSN (*Online*) 2581-0855
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