Coconut fiber strength test as a potential to prevent landslides on badlands

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Abstract. Landslide is one of the natural disasters that often occur on natural slopes. Landslides and erosion of slopes mostly happen during the rainy season, resulting in a decrease in soil shear strength. One method of reinforcing slopes is to use coconut fibers which have the features of fibers. Coconut fiber is not only relatively more economical but also can last a long time as a substitute for geosynthetics and even as a place for vegetation growth. The purpose of this study was to determine the tensile strength value of coconut fiber and to identify the shear strength of barren slopes and bush slopes on Takengon-Bintang-Blangkejeren Road, Bur Retak Area, Kampung Mendale, Central Aceh. The tensile strength testing of coconut fiber was carried out by taking into account the diameter size and the number of fibers. The tensile stress testing of coconut coir fibers was done by clamping both sides, with the diameter and the number of fibers varied. The results showed that the tensile strength (tr, MPa) of coconut coir fibers decreased with the increase in diameter and the number of the fibers. In the application, coconut coir fibers placed on a barren slope in one square meter area has the potential to produce additional shear strength.

1. Introduction

The failure of a slope can be related to several factors, such as weather conditions, soil type, slope angle, topography, or a combination of these. Slope failure is due to a decrease in the shear strength of the soil where the soil is unable to resist the shear stress that occurs when burdened. Soil shear failure happens not because of the destruction of the soil grains but the relative motion between the soil grains [1]. Landslides and erosion are examples of natural disasters related to slope failure.

Landslides are the displacement of slope-forming materials in the form of rocks, rubble, soil, or mixed materials, moving down or out of the slope. Shallow landslides often occur in the rainy season. Shallow avalanche incidents generally are on steep road cliffs, with the depth of the slide field is no more than two meters, and more often less than one meter. The shallow landslide usually links to a fairly high frequency of rain. Landslides are classified [2] into six types, namely translational landslides, rotational landslides, falls, topple, lateral spread, and the flows.

Landslides often occur worldwide, as well as in Indonesia, especially Aceh. Aceh Province is one of the areas where landslides frequently happen, such as in the Bur Retak area of Kampung Mendale, Kebayak, Aceh Tengah District, on March 31, 2014. This landslide caused the Takengon - Bintang - Blangkejeren causeway to be covered by large rocks. This incident also killed two university students
due to being hit by the rocks. This tragic incident encouraged the authors to research the method of slope strengthening.

One method of slope strengthening is using coconut mesh or coconut coir fiber. This technique is relatively inexpensive compared to other slope reinforcement methods, such as spray concrete, a term used for concrete that is shot and hardened in a relatively fast time (shotcrete).

Coconut coir fiber is widely used because of its long-lasting characteristics. It is very resilient, strong against friction, water-resistant, mold and pests resistant, as well as not easily broken, rot, nor inhabited by termites and rats (Rumokoi, 1990). Coconut coir fiber is also an alternative to composites development because it is not only cheap but also abundant. The area of coconut trees is around 3,712 million ha (Soba, 2003) or 3.88 million ha [3]. The islands of Sumatra, Java, Sulawesi and East Nusa Tenggara are the central areas for growing coconut trees, with an area of 2.841 million ha (76.5% of the total area of Indonesia). With the coconut area of 3.29 million ha [4], the potential for coconut production can reach an average of 15.5 billion per year. The total coconut fiber produced can reach up to 1.8 million tons. One coconut produces approximately 0.4 kg of coir, consisting of 30% fiber [5].

Coconut coir fiber consists of the chemical composition: cellulose, lignin, pyrolygenic acid, gas, charcoal, tar, tannin, and potassium (Rindengan et al., 1995). Cellulose is the main organic constituent of plant cell walls [6]. Hartati et al. (2013), in their research, reported that cellulose can increase the strength of coconut coir fiber. Lignin, the largest part of cellulose, has a major role in forming layers between the fibers that function as a binding between cellulose fibers in wood or non-wood [7]. From this composition, coconut coir fiber can also be used as a suitable medium for plant growth. Plants growing around coconut coir fibers help maintain the slope stability by increasing soil shear strength, estimated by measuring the root length density and soil shear strength at depths of 0 - 5 cm [8].

The combination of coconut coir fibers with native soil on the slope has the potential to increase the soil shear strength. The results of Lastiko's research [9] explained that coconut coir fibers could increase and increase the soil shear strength, as indicated by the variation of the soil mixture with 1.5% coconut coir fibers increasing the shear strength by 10.30%. Another study also [10] showed that the shear strength of the soil added coconut coir fibers was enhanced with an average increase of 3.32%. The shear strength of the original soil without coconut coir fibre was 53.50 kN/m² while for the soil with 5%, additional coconut coir, the shear strength was 64.05 kN/m².

This study aimed to determine the tensile strength of coconut coir fibers and identify the shear strength of the barren slope and bush slope overgrown with plants as a comparison of the shear strength of the original soil. The barren slopes studied were on Jalan Takengon-Bintang-Blangkejeren KM 10, Bur Retak Area, Mendale Village, Kebayaan District, Central Aceh Regency, Aceh Province. In further research, it is expected that the installation of coconut coir fibers can be installed at the location of this barren slope as additional cohesion of native soil to increase soil shear strength.

2. Research methods
The method used in data collection was through direct observation conducted by authors at the research location (primary data) and written information or document form (secondary data).

2.1. Primary data
Primary data included the tensile testing of coconut fiber, soil sampling in the field and testing in the laboratory.

2.1.1. Field testing. There were two activities undertaken in the field, examining the tensile strength of coconut fiber and sampling the soil at the location of the barren slope and the bush slope overgrown with plants.

2.1.1.a. Testing the tensile strength of coconut fiber. The tensile strength of coconut fiber stress testing was done by taking into account the diameter size and the number of fibers. The diameter of the coconut fiber was measured using a caliper tool. Before testing, coconut coir fibers were soaked in water until
saturated. The tensile stress testing of coconut coir fibers was done by clamping both sides (figure 1), with different diameters and fiber counts. This is measured by a Handifor 100 type recording device (maximum 100 N), as shown in figure 2.

This research had 100 samples with a combination of different diameters and a number of coconut fibers.

![Figure 1. Coconut Fiber tools test.](image)

**Figure 1.** Coconut Fiber tools test.

![Figure 2. Tensile strength of coconut fiber testing.](image)

**Figure 2.** Tensile strength of coconut fiber testing.

2.1.1. Field soil sampling. Soil sampling was carried out in two ways: disturbed sample for physical characteristics testing and undisturbed sample for mechanical characteristics. Soil retrieval was done by using a special tube of iron with open both ends. The sample was then brought to the Syiah Kuala University Soil Mechanics Laboratory for direct shear testing.

2.1.2. Laboratory testing

1. Physical Characteristics: soil water content, specific gravity (SG), soil volume weight, liquid and plastic limits, grain size analysis, permeability
2. Mechanical Characteristics: Direct Shear (Direct Shear Test)

2.2. Secondary data

Secondary data includes the map of the research location and daily rainfall data.

2.2.1. Location map. The location map illustrated the location of the study, a barren slope located on Jalan Takengon-Bintang-Blangkejeren KM 10, Bur Retak Area, Kampung Mendale, Kebayakan Sub-District, Central Aceh District, Aceh Province.

2.2.2. Rainfall data. Rainfall data was measured using a rainfall gauge. This rainfall data was obtained from the Geophysical Climatology Meteorology Agency (BMKG), Central Aceh District.

2.3. Data processing and analysis

The data on the tensile strength testing of coconut coir fibers and root pulling vegetation was analyzed using the Analysis of Variance (ANOVA) and the Microsoft Excel (2010) program to display data in the graph.
3. Results and discussion

3.1. Rainfall
One of the factors causing landslides on the slopes is rainfall. Based on observations from the Geophysical Climatology Meteorology Agency (BMKG) in Central Aceh District, the maximum monthly rainfall intensity in the last four years was in October 2014 (560 mm), while the minimum was in July 2014 (7 mm).

3.2. Physical characteristic of soil
The testing of the soil's physical characteristics was to classify the type of soil used in the study.

3.2.1. Soil characteristics. Soil moisture content was tested in three samples with the same type of soil. The test results revealed the average water content in the soil, and it can be concluded that the soil from the barren slope location contained 10.27% of water. Meanwhile, the bush slope location had 38.12% of water. These results indicate that the soil on the barren slope has a lower water content compared to the bush slope location. The results of specific gravity (SG) tests carried out in laboratories reported the values of the specific gravity were 2.66 and 2.57 for the barren slope location and the bush slope location, respectively. Test results and calculations revealed that the average weights of the soil volume were 1.85 grams/cm³ and 2.15 grams/cm³ at the location of the barren slope and the bush slope location, accordingly.

3.2.2. Soil characteristics. The American Association of State Highway and Transportation Officials (AASTHO) classifies soil into eight groups, A-1 to A-7. In classifying the soil with this method three soil parameters are needed, namely the liquid limit value (LL), the plasticity index value (PI) and the percentage of grain filter passing. The liquid limit value, plastic index and grain analysis, as shown in table 1

| Parameter            | Barren   | Bush    |
|----------------------|----------|---------|
| Liquid Limit LL (%)  | 32,79    | 53,31   |
| Plastic Limit PL (%) | 21,63    | 31,66   |
| Plasticity Index IP (%) | 11,16 | 21,64   |
| Pass #200 (%)        | 34,11    | 91,24   |
| Pass #40 (%)         | 52,04    | 93,54   |
| Pass #10 (%)         | 90,91    | 97,00   |

Based on table 1 and the American Association of State Highway and Transportation Officials (AASTHO) soil classification system, the soil at the barren slope location was included in group A-2-6, a type of sandy soil. As for the bush slope location, the soil was categorized into group A-7-5, a clay soil, the type of ordinary to bad.
3.2.3. Soil permeability. Permeability is the soil's ability to allow water to pass through the pores or the speed at which it moves the rate of a liquid in a porous media. Soil permeability values were obtained from the results of soil sample testing at the Soil and Environmental Physics Laboratory, Agricultural Product Engineering, Syiah Kuala University.

Table 2. Permeability testing result.

| Location     | Permeability (cm/hour) | Class |
|--------------|------------------------|-------|
| Barren Slope | 1.62                   | Medium|
| Bush Slope   | 1.59                   | Medium|

Table 2 presents the permeability test results, and it shows that the permeability values were 1.62 cm/hour and 1.59 cm/hour for the barren slope and bush slope location, respectively, and both were classified in the medium class. The greater the permeability value corresponds to the lower the ability of the soil to absorb water, meaning that more water will pass, and vice versa.

3.3. Soil mechanical characteristics

The mechanical characteristics of the soil, including the soil shear strength, was tested at the Soil Mechanical Laboratory, Civil Engineering, Syiah Kuala University.

3.3.1. Soil shear strength. The direct shear test results in this study generated the parameters of cohesion (c) and the internal friction angle (φ) from the relationship between the normal stress values and soil shear stresses. Before and after the direct shear test, measurements of initial and final water contents were measured. figure 3 is an example of the collapse path at the bush slope location 1.

![Diagram showing the collapse path on the Bush slope.](image)

**Figure 3.** The collapse path on the Bush slope.

Figure 3 shows that the collapse path on the bush slope location 1 as a line diagram connecting the domicile points of the soil sample condition at the time the test took place.

Table 3. Recapitulation of direct shear test results.

| Slope Location | Barren Slope | Bush Slope |
|---------------|--------------|------------|
|               | Point 1      | Point 2    | Point 3    | Point 1 | Point 2    | Point 3 |
| Cohesion (c)  | 0.165        | 0.185      | 0.180      | 0.375   | 0.380      | 0.370   |
| Internal friction angle (φ) | 28   | 36    | 27     | 20      | 18.5      | 20.5    |
Table 3 shows that the average of the shear angle (ϕ) at the barren slope location was 30.330, and the cohesion value (c) was 0.18 kg/cm². Meanwhile, for the bush slope location, the average shear angle (ϕ) was 19.670, and the cohesion value (c) was 0.375 kg/cm².

3.4. Tensile strength of coconut coir fiber

The tensile strength testing of coconut coir fiber revealed the graphical relationship between the tensile strength of the fibers and the diameter and number of fibers.

3.4.1. The relationship of the number of coconut fiber and fiber tensile strength. Figure 4 shows that the tensile strength of the fiber significantly increases with the increase in the number of fibers. The fiber tensile strength depended on the number of fibers, even if the influence of the diameter of each fiber was different. Equation (1) displays an equation based on the relationship of the tensile strength (Tr) and the number (n) of coconut coir fibers.

\[
Tr = 0.0078n + 0.0003 \quad R^2 = 0.9634
\]

Figure 4. The relationship of number (n) coconut fibers with the tensile strength of fiber (Tr).

Figure 5. The relationship of diameter (d) of coconut fiber with the tensile strength of fiber (Tr, MPa).
3.4.2 Relationship of fiber tensile strength with fiber diameter. Figure 5 illustrates the relationship between the diameter (d) of coconut fiber and Tensile Strength (Tr). The analysis shows that the fiber tensile strength increases significantly with the increase in the fiber diameter. Based on figure 5, the following equation is created.

\[ Tr = 0.0078n + 0.0003 \quad R^2 = 0.9634 \]

(2)

3.5. Tensile strength of coconut fiber

The tensile strength of fibers is highly influenced by the diameter of each fiber, as shown by the fiber tensile strength equation (3).

\[ tf = \frac{4F}{\pi d^2} \]

(3)

Where:
- \( tf \) = tensile strength of individual fibers (MPa);
- \( F \) = maximum load at the breaking point (N); and
- \( d \) = average fiber diameter at three points (mm).

The results of tensile strength testing of coconut coir fibers generated the graphical relationship between the fiber tensile strength, the number of fibers and the diameter of fibers.

3.5.1. Relationship of the amount of coconut fiber with fiber strength. Figure 6 indicates the relationship between the tensile strength (tr, MPa) and the number (n) of coconut coir fibers and it shows that the strength of coconut coir fibers significantly decreased at the test limit of fewer than five fibers, with different diameters of each fiber. Meanwhile, when more than five fibers were used, with different diameters of each fiber, the strength did not significantly decrease.

![Figure 6](image_url)

Figure 6. The relationship of number of coconut fiber (n) with tensile strength of fiber (Tr, MPa).

An equation based on the relationship of strength (tr) and the number (n) of coconut fibers is as follows.

\[ tr = 23,226n - 1,041 \quad R^2 = 0.9874 \]

(4)

3.5.2. Relationship of the diameter of coconut fiber with fiber strength. Figure 7 shows that the strength of coconut fiber significantly decreased when the diameter was less than three, and it began to stabilize with a diameter of more than three. Thus, based on the relationship of the fiber strength (tr, MPa) and the diameter (d) of coconut coir fibers in figure 7, the following equation was generated.
Figure 7. The relationship of the diameter (d) of the coconut fiber and the fiber strength of (tr, MPa).

\[ tr = 15.687n - 1.045 \quad R^2 = 0.9835 \]  

3.6. Tensile strength of cocomesh anova analysis results

Based on the ANOVA, the F value of the calculated tensile strength of coconut coir fibers is presented in table 4.

| No | Diameter (mm) | Calculate F Value | Table F Value |
|----|---------------|-------------------|---------------|
| 1  | 0.63          | 18.12             | 18.51         |
| 2  | 0.64          | 94.79             | 161.00        |
| 3  | 0.65          | 6.19              | 18.51         |
| 4  | 0.66          | 112.04            | 161.00        |
| 5  | 0.67          | 6.61              | 6.62          |
| 6  | 0.68          | 5.84              | 6.62          |
| 7  | 0.69          | 12.38             | 18.51         |
| 8  | 0.70          | 5.67              | 5.99          |
| 9  | 0.71          | 16.10             | 18.51         |
| 10 | 0.72          | 6.60              | 161.00        |

Table 4 shows that the F_{count} is smaller than F_{table}. It means that the fiber tensile strength decreases when the fiber diameter is large, but it is not significant.

3.7. Discussion

Rainfall is one of the triggers for landslides with certain slope conditions. Continuous high rainfall has the potential for landslides, as in this condition, the saturation of the soil by water increases the mass of the soil. The observation results of the Geophysical Climatology Meteorology Agency (BMKG), Central Aceh Regency, showed that the cumulative rainfall intensity in the last four years (from January 2013 to 2016) was 8072 mm. The highest monthly rainfall intensity was in October 2014 (560) mm. This rain intensity is included in the criteria of very heavy rainfall, based on the classification of rainfall of the international standards of the World Meteorological Organization (WMO) (Susilowati, 2010).

Based on the classification results of the AASHTO and USCS systems, the type of soil at the barren slope location is silt sand, while it is clay for the bush slope location. This classification shows that the water content on the barren slopes is smaller than on the bush slopes overgrown with plants. This is in
agreement with the test results revealing that the soil water content on the barren slope and the bush slope was 10.27% and 38.12%, respectively.

The results of the direct shear test generated the value of the deep shear angle ($\phi$), with the average at the barren slope location was 30.330, and the cohesion value ($c$) was 0.18 kg/cm². On the other hand, for bush slope locations, the average shear angle ($\phi$) was 19.670, and the cohesion value ($c$) was 0.375 kg/cm². These figures show that the location of the barren slope has a lower shear strength than that of the bush slope, which is at risk of landslides.

The focus of this study is the testing of cocomesh. The test results show that the tensile strength of the fiber increases with the increasing number and diameter of the fiber significantly. While the tensile strength of the fiber (tr) decreases with increasing number and diameter of the fiber. This is evident from the graphic relationship between the tensile strength (tr, Mpa) and diameter (mm) of the fibers in figures 4.8 and 4.9. Anova analysis shows that the tensile strength of the fiber decreases, although not significantly.

In its application, coconut coir fibers will be formed like a net or commonly called Coir Geotextile to strengthen the soil structure. It can also be a medium for growing various types of plants. These coconut coir fibers will be placed on the sloping land or barren rocky slopes. The nature of the coconut coir fibers can store water for a long time, causing the soil surface covered by this material to retain its moisture. This circumstance can affect the structure of the soil so that it is easy to plant seeds. Hence, the combination of coconut coir fibers and Based on the classification of the Unified Soil Classification System (USCS), the classification of soil at the barren slope location indicates that the fine-grained soil types was greater than 50%, based on the percentage of filter passing No.200. Based on the results of the plot in the USCS classification table, the soil at the location of the barren slope was classified in SC type, soil containing silt sand. Whereas, the soil at the bush slope location was classified in CH type, contains inorganic clay. Clay soil on a barren slope has the potential to increase the shear strength of the soil.

4. Conclusions
Based on the results of the discussion on the strength test of coconut coir fibers to prevent landslides on barren slopes, the following conclusions can be drawn:
1. The cohesion value ($c$) and the average shear angle ($\phi$) from the results of the direct shear test show that the barren slope location has a lower shear strength compared to the bush slope location.
2. The tensile strength (tr, Mpa) of coconut coir fibers will decrease with the increase in the number and the diameter of fibers.

References
[1] Santosa B, Suprapto H and Suryadi 1998 Basic Soil Mechanics (Jakarta: Gunadarma)
[2] Nandi 2007 Avalanche Department of Geography Education (Bandung FPIPS-UPI)
[3] Angkriawan C 2007 Indonesia still ignores the potential of coconuts Daily Newspaper Daily Update Voice
[4] Suryana A, Prastowo B, Mahmud Z, Wahyudi S, Hardono G S, Novarianto H, Luntung H T and Rfendi D S 2007 Prospects and direction of coconut agribusiness development 2nd Edition Agency for Research and Development, Agriculture Ministry of Agriculture
[5] Mahmud Z dan Ferry Y 2005 Prospects for Processing Coconut By-products. J. Perspektif 4
[6] Ferra Fahriani 2016 Analysis of Soil Stability with Strength of Coconut Fiber J. of Bangka Belitung University
[7] Paskawati, Yessica A et al. 2010 Utilization of Coconut Fiber as Raw Material for Making Alternative Composite Paper Technical J. 9 1 12-21 (Surabaya: Widya Mandala Catholic University)
[8] Abe K and Ziemer R R 1991 Effect of tree roots on shallow-seated land slides USDA forest Service Gen. Tech. Rep. PSW-GT 130: 11-20
[9] Lastiko L J, Haja Z F and Sulistyorini D 2017 Soil Stability Using Coconut Fibers Through Direct
Shear in the laboratory J. of Sarjanawiyata (Yogyakarta: University Taman Siswa)

[10] Ridwan 2014 *Effect of Coconut Fiber Addition to Clay Soil Strength* (Thesis. Department of Civil Engineering, Bangka Belitung University)