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The use of natural fiber from oil palm empty fruit bunches for soft soil stabilization

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Abstract. The use of natural fiber as a construction material, especially soil stabilization continues to grow. This paper focuses on the use of natural fiber to increase shear strength and bearing capacity of soft soil. The fiber used is obtained from oil palm empty fruit bunches (EFB) as a by-product of palm oil mills. Soft soil mixed with fiber with a composition of 5, 6, 7, and 8% fiber in the mixture. Some tests such as the standard compaction test, unconfined compression test, laboratory vane test, and California Bearing Ratio test were carried out. The results show that the soft soil used in this study can be compacted at fiber content higher than 5%. The maximum density obtained is 0.92 g/cm³ at 7% fiber content. The compacted soil-EFB mixtures successfully increase the shear strength and bearing capacity of the soft soil shown by the results of the UCT, laboratory vane, and CBR tests. The soil consistency changes from soft to medium soil. The maximum q_u , s_u , and CBR obtained are 0.8 kg/cm², 0.65 kg/cm², and 6%, respectively at optimum fiber content of 6 to 7%.

1. Introduction

The use of fiber for construction materials has been carried out, especially for increasing the strength of concrete [1, 2, 3]. Addition of steel fiber to concrete increases strength and maximum displacement, and also reduces the number of cracks in concrete [2]. Fiber is also developed for soil stabilization using either synthetic fibers such as tire shredders [4], Nylon fiber [5], polypropylene fiber [6, 7], glass fiber [8], basalt fiber [9], as well as natural fibers such as coir fiber [10], wheat straw, barley straw, and wood shaving [11], and bamboo fiber [12].

Ignoring whether fiber is used synthetic or natural, soil stabilization with fiber is influenced by fiber content [4, 5, 6, 7, 8, 9, 11, 12, 14, 16], fiber length [7, 9, 12, 16], water content [14], fiber characteristics [15, 8, 11], fiber diameter [12], soil properties [5, 15], and stress conditions [4, 10, 15].

The interaction between soil and fiber is interesting to learn in improving the nature of soil engineering. [13] stated that fiber-reinforced soil shear strength has two components, including the shear strength of the soil matrix and the tensile stress acting on the fibers. Besides that, [14] stated that the bonding of soil and fiber caused the contribution of fiber to the increase in shear strength to the pull out the mechanism and the tensile strength of the fiber itself. This mechanism explains the interaction of soil and fiber in general, where other possible interactions occur between soil and fiber, especially for natural fibers. [11] found that natural fiber absorbs more water than the soil. This behavior is needed, especially for the stabilization of soft soils that have high water content.



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Some other advantages of using natural fiber are environmentally friendly alternatives, locally available, can create composites with cement/lime, inexpensive, and biodegradable [5, 17]. Therefore, this paper discusses the alternative use of natural fiber from oil palm empty fruit bunches (EFB) for stabilizing soft clay soils. The fibers are a byproduct of the palm oil industry. The use of this fiber as an alternative to soft soil stabilization is rarely discussed. [18] has succeeded in increasing the strength of laterite brick slightly by adding 3% EFB in the mixture of laterite, sand, and cement.

For applications in the field, fiber reinforcement is possible to repair slopes and strengthen thin layers of soil where synthetic materials such as geotextiles and geogrids are challenging to implement [13]. Fiber can also be used to stabilize subgrade soil from sand to high plasticity clay [20]. Therefore, this paper focuses on providing new information about the possibility of using natural fiber from an oil palm empty fruit bunch as soft clay reinforcement material.

2. Material used

2.1. Soil

The soft soil used was taken near the city of Banjarmasin, the capital of South Kalimantan. The soft soil characteristics are summarized in Table 1. The physical properties were determined using the tests based on ASTM standards [21]. The soft clay was classified as an organic soil with high plasticity (OH) based on USCS classification system.

Table 1. Summary of soft soil characteristics used

Properties		Soft soil
Specific gravity		2.31
Water content	%	106.07
Liquid limit	%	61.00
Plastic limit	%	34.87
Plasticity index	%	26.13
Fine content	%	95.12
Clay content	%	56.32
Soil type	USCS	OH

2.2. Fiber

The fiber used is oil palm empty fruit bunches (EFB) as a byproduct of palm oil processing in PT. Perkebunan Nusantara XIII, Pleihari (Figure 1 (a)). The fiber has a water content of 9.8% and the density of 0.45 g/cm³, as shown in Table 2. The fiber density is smaller than that reported by [18]. However, the value is very close to the realistic density of natural fibers of coil and sisal (i.e., 0.67-1.07 g/cm³) as reported by [19]. The fiber has a diameter of 200-500 μm measured from the SEM image (Figure 1(b)) and rough surface, as shown in Figure 1 (c).

A test was carried out to determine the water absorption of EFB used by soaking it for one, two, and three days. The results are shown in Table 2. After soaking, the fiber moisture content increases to 384.99% and does not change significantly on the second and third days with water levels of 422.71% and 415.87%, respectively. The result confirmed previous findings that the fibers absorb more water than soil and continue to increase with increasing fiber content [11].

3. Techniques and procedures

In sample preparation, the size of fiber used varies depending on the test performed. For compaction, CBR, and vane tests, the fiber length used was a maximum of 10 cm or smaller than the mold size used (i.e., 11.51 cm). For the UCT test, a 1 cm fibers size was used to adjust the diameter of the sample used (i.e., 4.77 cm).

Because the soft soil used had very high water content, the initial test was performed to determine the percentage of fiber at which compaction can be carried out. Based on trial tests, the mixture can be

compacted at the fiber content of 5%. The compositions of fiber used in this study were 5, 6, 7, and 8%. Moreover, four types of specimens were prepared with different EFB contents (on a dry mass base); namely, 5% EFB, 6% EFB, 7% EFB, and 8% EFB. The specimens were dynamically and statically compacted depend on the tests performed.

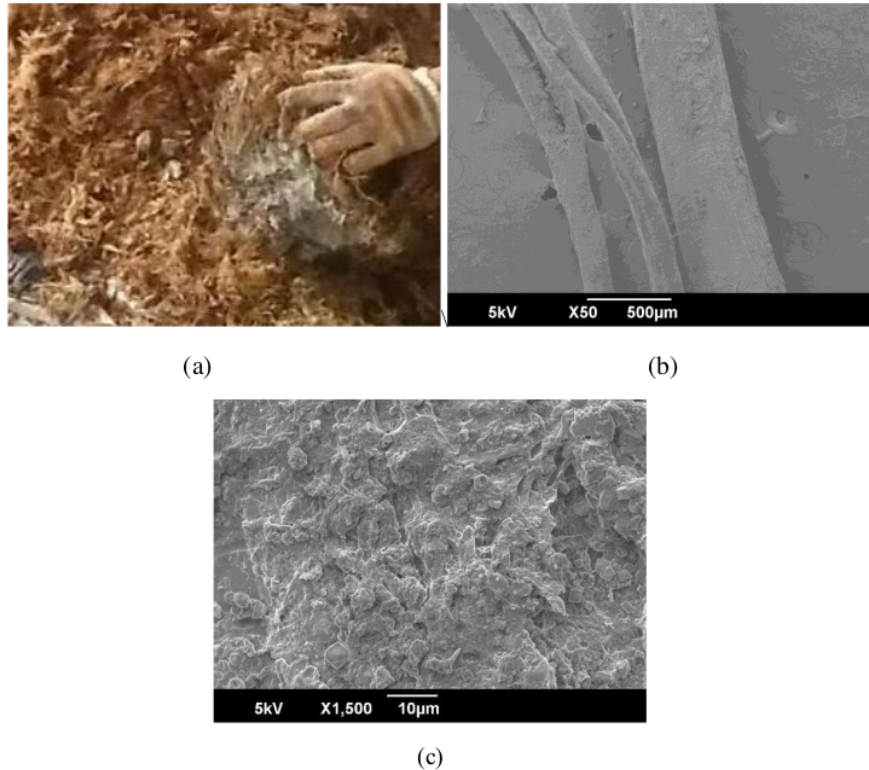


Figure 1. EFB fiber (a) raw material, and SEM image with a magnification of (b) 500×, and (c) 1500×

Table 2. Summary of fiber from empty fruit bunches (EFB) characteristics used

Properties		EFB fiber
Water content	%	9.8
Density	g/cm ³	0.45
Water absorption:		
one day	%	384.99
two days	%	422.71
three days	%	415.87


Some test techniques used include standard Proctor compaction test, California bearing capacity (CBR) test, and laboratory vane tests (using dynamically compacted samples) and unconfined compression tests (using statically compacted samples).

To ensure fiber distribution in the sample is evenly distributed, a trial test was conducted on the sample by dividing it into three parts, namely top, middle, and bottom. The soil and samples were separated by soaking in water. The dry weight of fiber and soil were compared. The results are shown

in Table 3. The fiber contents in the sample were evenly distributed with an average of 5.07% and 5.99% for samples of 5% EFB and 6% EFB, respectively.

Table 3. Fiber distribution in the samples

Fiber percentage plan	5%	6%
Top	5.12	5.96
Middle	5.02	6.02
Bottom	5.08	5.99
Average	5.07	5.99



4. Results and discussions

4.1. Compaction test

Table 4 shows compaction test data using standard Proctor for samples with fibers content of 5, 6, 7, and 8%. Compaction was performed by three layers and 25 blows per layer. There are two fundamental things obtained from Table 4; there are changes in water content and sample density. The water content of the sample decreases with increasing fiber content to a 7% EFB, as shown in Figure 2 (a). This reduction in water content was due to the addition of fiber that fills the soil pores. The figure also shows that the sample that can be compacted has moisture content smaller than the liquid limit. At high water content, the pore water pressure increases in compaction proses so that fiber does not contribute much to this condition. This agrees well with the findings reported by [14].

Table 4. Optimum fiber content determination

Fiber content	%	5	6	7	8
No. of layers		3	3	3	3
No. of blows		25	25	25	25
Density	g/cm ³	1.365	1.392	1.382	1.307
Water content	%	62.40	56.98	51.05	51.51
Dry density	g/cm ³	0.84	0.88	0.92	0.87

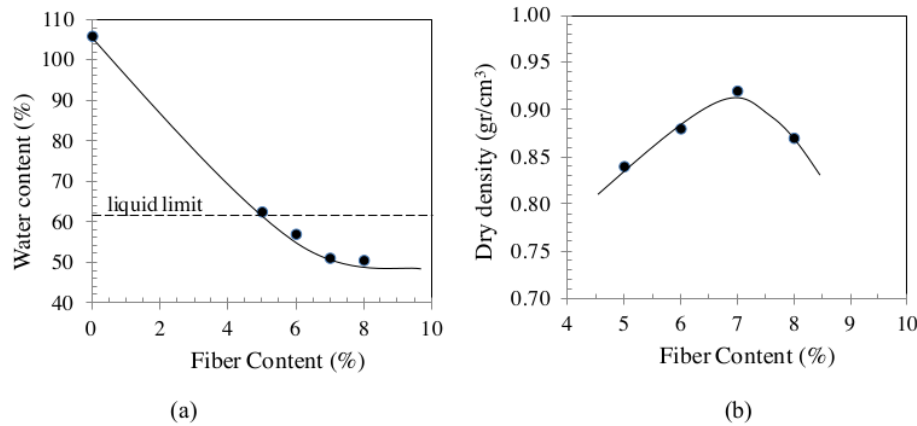


Figure 2. (a) Water content and (b) dry density of samples as a function of fiber contents

Figure 2 (b) shows sample density as a function of fiber content. Soil density increases to 7% fiber content with a density of 0.92 g/cm³. The smaller density was obtained at 8% fiber content. When the

soil has begun to be plastic (i.e., water content less than liquid limits), the bond between fiber and soil has begun to form. The more fiber, the higher the soil-fiber bonding due to pull-out. While at 8% fiber content, the interaction of soil and fiber decreases because the amount of fiber reduces the bonds between soil and fiber. In this condition, compaction is difficult to perform, and the large pores appear in the sample. Visually, Figure 3 shows pictures of compacted samples for each percentage of fiber.

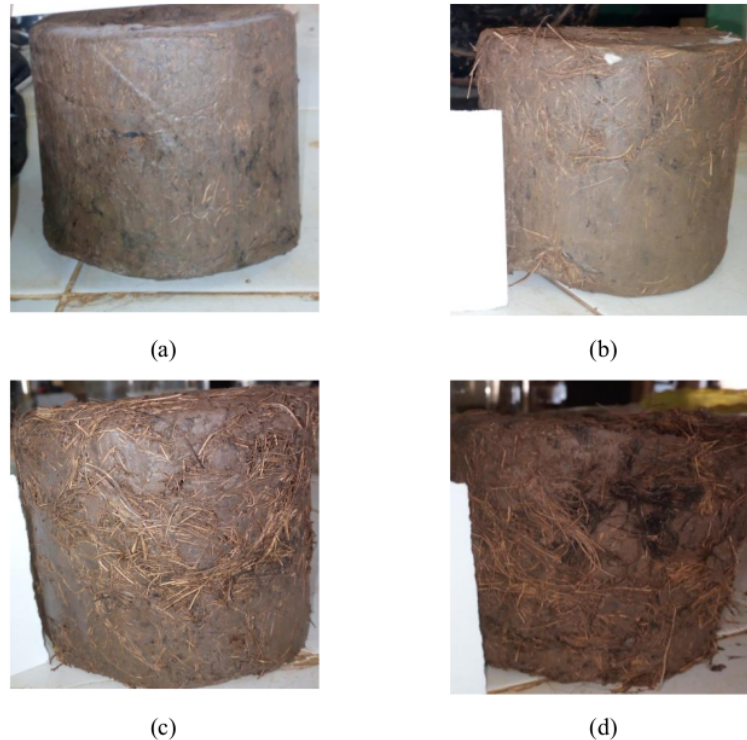


Figure 3. The photograph of samples compacted at different fiber content (a) 5% EFB, (b) 6% EFB, (c) 7% EFB, and (d) 8% EFB

4.2. Unconfined compression test

The unconfined test was performed to a statically compaction specimen due to the presence of fiber. The sample with a diameter of 4.75 cm and 9.24 cm high were used. The result obtained from the test was unconfined compression strength (q_u). Figure 4 shows the q_u as a function fiber content. Consistent with compaction result, the q_u increases by increasing fiber content. The peak of q_u (i.e., 0.8 kg/cm²) was obtained at the fiber content of 7%. The value decreases at 8% fiber content. The result reveals that the presence of fiber changes the soil consistency from very soft to medium soil based on [22] (i.e., medium soil 0.48-0.96 kg/cm²).

4.3. California bearing ratio test (CBR)

Figure 5 shows CBR as a function of fiber content. Different from compaction and q_u results, the maximum CBR of 6% was obtained in between 6 to 7% fiber content (i.e., 6.4%). Random distribution of fiber may result in optimum fiber content shifted between 6 and 7%. Consistent with UCT, the

presence of fiber and compaction results in increasing bearing capacity of soil from very soft to CBR of 6%.

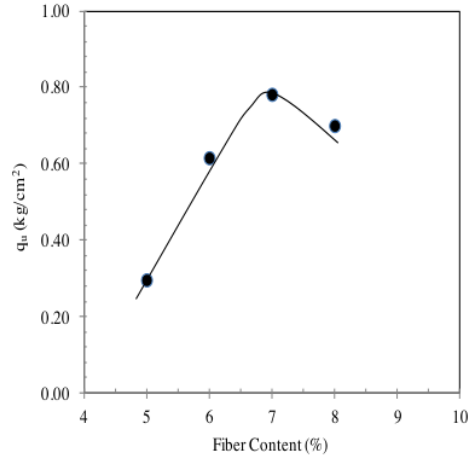


Figure 4. q_u as a function of the fiber content

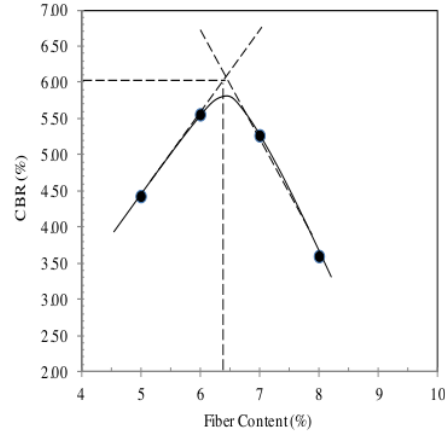


Figure 5. CBR as a function fiber content

4.4. Laboratory vane test

To avoid the vane being resisted by fiber as reported by [17], the small vane of 1.85 cm was used. Figure 6 shows undrained shear strength (s_u) obtained from laboratory vane test at different compaction energy. As shown in the figure, the maximum s_u of soil compacted by 10 and 25 blows are 0.46 kg/cm² and 0.65 kg/cm² placed at the fiber content of 6%. The energy of 25 blows is a standard Proctor compaction energy. The result reveals that the optimum fiber content obtained from laboratory vane test gives the smallest optimum fiber content. The smaller vane used in this study may result in reducing the fiber contribution in the mixtures. The test was measured the shear strength of soil between fiber; it was entirely the shear strength of soil-fiber mixtures. By increasing the compaction energy (i.e., 56 blows), the s_u increases to 0.71 kg/cm² at the fiber content of 6.7% approximately.

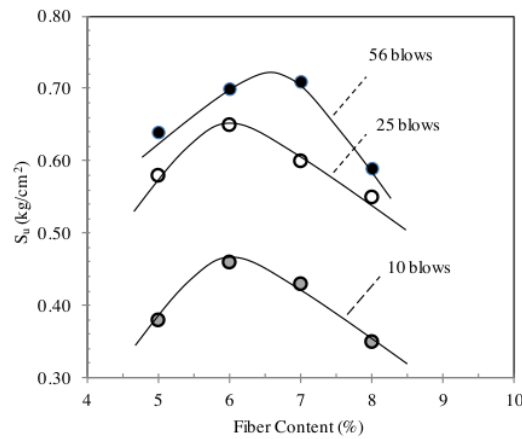


Figure 6. Undrained shear strength as a function fiber content

5. Conclusion

The effects of natural fiber made from oil palm EFB in enhancing soft soil shear strength were presented. Several important findings obtained from the study are:

- EFB function is not only as fiber to increase shear strength but also absorbs water, allowing soft soil to be compacted.
- The soft soil used in this study can be compacted at fiber content higher than 5%. The maximum density obtained is 0.92 g/cm³ at 7% fiber content.
- The compacted soil-EFB mixtures successfully increase the shear strength and bearing capacity of the soft soil shown by the results of the UCT, laboratory vane, and CBR tests. The soil consistency changes from soft to medium soil.
- The maximum q_u , s_u , and CBR obtained are 0.8 kg/cm², 0.65 kg/cm², and 6%, respectively at optimum fiber content of 6 to 7%. Other paragraphs are indented (BodytextIndented style).

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