RESEARCH ARTICLE OPEN ACCESS

Unlocking the Potential of Pineapple Leaf Fiber Extract Through the Process of Boiling and Bleaching: A Research into Its Application as an Additive for Soil Stabilization in Bacolor, Pampanga

Matt Jayson G. Manalang[1], Andrea B. Carreon[2], Aira G. Magpayo[3], Danwell D. Manarang[4], Bridgette P. Manuel[5], Ma. Lois G. Dela Cruz[6], Irene R. Roque[7]
[1]Department of Civil Engineering, Don Honorio Ventura State University, Villa de Bacolor, Pampanga
Email: 2020100236@dhvsu.edu.ph

--************************----------------------------------

Abstract:
This study investigates the potential of utilizing pineapple leaf fiber extract (PLFE) as a sustainable soil stabilizer, focusing on soil in Bacolor, Pampanga, Philippines. Pineapple fiber, derived from Ananas comosus leaves, is often discarded post-harvest, posing environmental threats due to its high biodegradability and methane emissions in landfills. PLFE's cellulose content provides high strength and stiffness, making it suitable for stabilization due to cellulose's adhesive properties and high water retention. The research examines soil treated with PLFE, which was boiled at 118°C for lignin removal and bleached using sodium hydroxide to enhance cellulose content. PLFE percentages of 0%, 4%, 8%, and 12% were tested through the Atterberg Limit Test, Standard Proctor Test, and California Bearing Ratio (CBR) Test. Upon testing, it was revealed that the soil sample had no plastic; therefore, the soil used was identified as silty soil, falling under the A-4 type of soil according to the AASHTO classification. Standard Proctor Test results showed that 12% additives yielded better outcomes, with Maximum Dry Density increasing from 1519 kg/m³ to 1536 kg/m³ for boiled PLFE and to 1554 kg/m³ for bleached PLFE. Optimum Moisture Content decreased from 24.4% to 21.1% for boiled PLFE and to 20.6% for bleached PLFE. The CBR Test results indicated that boiled PLFE did not meet the standard CBR value (5%-15%) as it decreased from 8% to 2%, while bleached PLFE succeeded in meeting the standard for all specimens, increasing from 8% to 15% for the 12% PLFE additive. Percent swell results showed a low degree of expansion for both treatments, with bleached PLFE achieving a lower result. Laboratory experiments revealed that boiled PLFE improved soil compaction but decreased CBR values, likely due to changes in soil structure. In contrast, bleached PLFE showed superior results, enhancing soil parameters in both Standard Proctor and CBR tests.

Keywords **—Cellulose, Bleaching Process, Boiling Process, Pineapple Leaf Fiber Extract, Soil Stabilization**

--************************----------------------------------

I. INTRODUCTION

Soil is a natural, unconsolidated mixture of mineral particles, organic materials, water, air, and a variety of living things. To comprehend the behavior of soil, engineers examine its composition, strength, density, and permeability. Civil engineers face a substantial challenge because not all soils are appropriate as a foundation for structures. The soil type in Bacolor, Pampanga, where the study will be conducted, is Angeles Fine Sand. This soil comprises 79.5% sand, 14% silt, and 5.5% clay bur [1]. This soil is classified as Loamy Sand using the United States Department of Agriculture (USDA) Soil Texture Triangle. On the other hand, the soil sample will be collected at a depth of 0.2 m to 4 m from the ground surface, [2], in Barangay Sta. Ines, Bacolor, Pampanga, Philippines. Pampanga is a province in Central Luzon known for its rich agricultural legacy, and Barangay Sta. Ines in Bacolor was selected as the specific location for obtaining soil samples due to its representative soil qualities. Soil stabilization is an essential component of geotechnical engineering, especially in construction and infrastructure development, rendering it more appropriate for construction applications [3].

Soil stabilization refers to the process of enhancing the engineering properties of soil to improve its strength, durability, and load-bearing capacity. To improve the soil's engineering qualities and make it suitable for use as a building foundation, soil stabilization entails the addition of different materials or additives [4]. These additives can be divided into many groups according to their characteristics and impact on the soil. Commonly, chemical additives are used in soil stabilization, and synthetic polymers are used to modify soil properties.

Engineers have already tried many chemical additives encompassing various approaches to improve soil properties for construction purposes. Lime stabilization, a widely used method, alters soil by adding lime, adjusting pH levels, reducing plasticity, and bolstering load-bearing capabilities [4]. Natural fibers obtained from diverse plant sources like coir or sisal present a great opportunity to improve the soil's technical qualities for use in construction [5]. By adding these fibers (commonly rice husk, coconut coir, and jute) to soil matrices, traditional stabilizing techniques can be replaced with a more sustainable one that increases stability. Therefore, the researchers are examining the potential effects of incorporating pineapple fiber for soil stabilization.

Pineapple fibers are efficient additions for soil stability because they include cellulose, which makes up about 70-82% of the fibers [6]. The cellulose content of PLFE is greater than that of water hyacinth, mengkuang (screw pine) leaves, and oil palm empty fruit bunch (OPEFB). Cellulose, when utilized in large quantities, may bind soils and increase their mechanical strength [7]. Because of its fibrous structure, cellulose has a high water retention capacity and strong adhesive characteristics. Because of its fibrous threads, cellulose has a viscoelastic quality that improves soil cohesiveness and geotechnical characteristics [8]. Cellulose is a popular stabilizer for soil stabilization applications because of its property. However, there is a major environmental problem with pineapple waste, which accounts for 50 to 65% of the fruit. A significant portion of pineapple plants, the leaves, are often allowed to rot or burn until they completely decompose, which typically takes around 35 weeks [10]. Finding a better way to dispose of pineapple leaves is the primary goal of this research.

II. METHODOLOGY

A. *Chemical Stabilization*

Chemical stabilization is a process that involves the use of both conventional and non-conventional binders to stabilize soil. Conventional binders like lime and cement are commonly used, along with non-conventional binders such as fly ash, rice husk ash, ground granulated blast-furnace slag, and silica fume. In order to make up the high water-to-cementratio that causes a lot of heat of hydration duringconventional stabilization, which can cause soilfailure and structural instability, an additionalamount of stabilizer (5–10%) is frequently needed.However, the use of non-conventional binders made from agricultural and industrial by-products can provide an alternative to conventional binders, as they allow for gradual hydration and can partially replace conventional binders [11].

B. *Fiber Extraction*

To extract PLFE, the epidermal tissue of the leaves is removed [12]. Due to the waxy coating on the surface of the fiber, machine extraction is preferred. Manual extraction is used to extract fibers from leaves. The fibers are then brushed with a comb to separate the fine threads from the spongy ones, and finally, the fibers are knotted by hand, washed, and dried in the sun for 48 hours.

C. *Cellulose*

Pineapple leaf fiber has a cellulose content of 70-82% and a tensile strength of 413-1627 MPa to stabilize the soil [13]. Moreover, the cellulose content of pineapple crown leaf waste was reported to be between 79-83% [14]. Cellulose derived from pineapple leaves preserved its original structure and was highly crystalline [15]. These studies show cellulose derived from pineapple leaf fiber can efficiently stabilize soil by increasing its strength and decreasing hydraulic conductivity in soil. Therefore, cellulose fibers can enhance the cohesion of soil particles. When added to soil, cellulose helps bind the particles together, increasing the strength and stability of the soil.

D. *Boiling Process*

Degradation of lignin in pineapple leaves occurs within the temperature range of 90–230°C. Beyond this range, the cellulose component begins to decompose, with significant decomposition occurring above 230°C, and the majority of it breaking down by 350°C. Applying pressure during cooking can elevate the solvent's boiling point to 118°C, enhancing lignin removal. This implies a correlation between lignin content and tearing strength, indicating that reduced lignin levels lead to increased tearing resistance and improved paper quality [20]. These treatments effectively removed residual lignin and hemicellulose from the cow dung, which underwent boiling for 2 hours at 90 degrees Celsius [21]. Decomposition occurs more rapidly in soils with the right balance of moisture and temperature due to increased microbial activity.

E. *Bleaching Process*

The objective of this study was to produce cellulose from PLFE using chemical treatment. Recently, much work has been done on pre-treatment to extract cellulose. These processes may increase the accessibility of cellulose using this treatment. Therefore, in this study, PLFE was treated with different retention times of steam treatment followed by different temperatures of bleaching treatment to maximize the removal of hemicellulose and lignin with less degradation of cellulose [17]. Bleaching helps improve the cellulose content of pineapple fiber [18]. A 6% solution of sodium hydroxide is prepared, and the fibers are soaked in it for approximately 5 hours. The fibers are then rinsed to eliminate any excess bleaching solution [19].

F. *Soil Sample, Design Mixture, and Tests for Stabilization*

The soil sample utilized in the experiment was obtained 2 to 3.5 meters below the ground surface at Sta. Ines, Bacolor, Pampanga. Loamy sand has a high sand percentage, but the small proportion of silt and clay results in a better water and nutrient-holding capability than sandy soils [16]. Only the fine-grained portion of the soil, passing through sieve no. 4 and sieve no. 40, will be utilized in the actual testing. Moreover, the proportions of additives are 0%, 4%, 8%, and 12%, and the tests that will be performed are in line with ASTM standards, limited to laboratory results. These tests include the Atterberg Limit Test (ASTM D4318-17e1), Standard Proctor Test (ASTM D698-12), and California Bearing Ratio Test (ASTM D698-12), as field tests cannot be done due to cost and time constraints.

TABLE I
PROPOSED STABILIZING DESIGN MIXTURE FOR ATTERBERG LIMIT TEST

Materials				
Specimen	1 (0%)	2 (4%)	3 (8%)	4 (12%)
No. of Trial	3	3	3	3
Soil	150g	150g	150g	150g
Bleached PLFE	0	6g	12g	18g
Boiled PLFE	0	6g	12g	18g

TABLE IIIII
PROPOSED STABILIZING DESIGN MIXTURE FOR STANDARD PROCTOR TEST

Materials				
Specimen	1 (0%)	2 (4%)	3 (8%)	4 (12%)
No. of Trial	4 to 5	4 to 5	4 to 5	4 to 5
Soil	6000g	6000g	6000g	6000g
Bleached PLFE	0	240g	480g	720g
Boiled PLFE	0	240g	480g	720g

TABLE IVVVI
PROPOSED STABILIZING DESIGN MIXTURE FOR CALIFORNIA BEARING RATIO TEST

Materials				
Specimen	1 (0%)	2 (4%)	3 (8%)	4 (12%)
No. of Trial	1	1	1	1
Soil	8000g	8000g	8000g	8000g
Bleached PLFE	0	320g	640g	1920g
Boiled PLFE	0	320g	640g	1920g

III. RESULTS AND DISCUSSION

TABLE VIIV
ATTERBERG LIMIT, COMPACTION, CBR SWELL AND CBR TEST RESULTS FOR BOILED PLFE

SPECIMEN	Plasticity Index	SOIL CLASS.	MDD	OMC	% Swell	CBR
CONTROL	Non-Plastic	A-4	1519	24.4	0.24	8
4% BOILED	Non-Plastic	A-4	1528	23.42	0.21	6
8% BOILED	Non-Plastic	A-4	1529.9	23.1	0.5	4
12% BOILED	Non-Plastic	A-4	1536	21.1	1.57	2

TABLE V
ATTERBERG LIMIT, COMPACTION, CBR SWELL AND CBR TEST RESULTS FOR BLEACHED PLFE

SPECIMEN	Plasticity Index	SOIL CLASS.	MDD	OMC	% Swell	CBR
CONTROL	Non-Plastic	A-4	Silty Soil	1519	24.4	0.24
4% BLEACHED	Non-Plastic	A-4	Silty Soil	1533.5	22.9	0.2
8% BLEACHED	Non-Plastic	A-4	Silty Soil	1545	22.2	0.27
12% BLEACHED	Non-Plastic	A-4	Silty Soil	1554	20.6	0.81

In the Atterberg limit test of the soil, the personnel of the DPWH Regional 3 office performed the procedure for determining the plasticity index of the soil sample. The soil from Sta. Ines, Bacolor, Pampanga, could not be rolled down at any moisture level, so it was considered non-plastic. In simple terms, the plastic limit (PL) is identified by rolling out a thread of the fine portion of soil on a flat, non-porous surface [22]. The plastic limit is determined by the moisture content at which the thread breaks apart with a diameter of 3 mm. Soil is classified as non-plastic if it cannot be rolled out to a diameter of 3.2 mm at any moisture level [23].

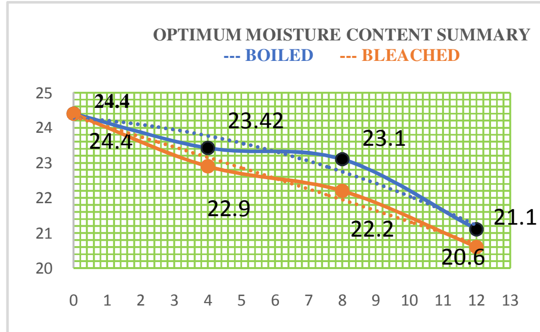

Fig. 1. Optimum Moisture Content Summary

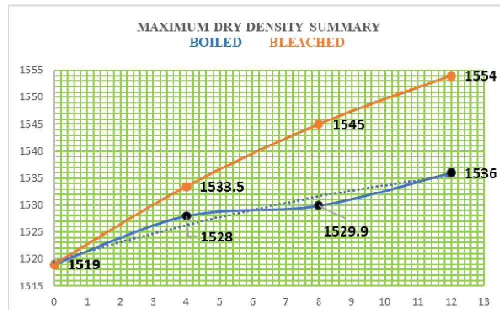

Fig. 2. Maximum Dry Density Summary

Figure 1 and Figure 2 illustrate that in Standard Proctor Test of Boiled PLFE showed that the increased Maximum Dry Density (MDD) of the sample led to a decrease in the Optimum Moisture Content (OMC) of the 12% Boiled PLFE. The 3rd sample which had an 8% Boiled PLFE mixture showed a significant increase in Maximum Dry Density (MDD); which may be caused by continuous testing of the possible Maximum Dry Density as the sample was tested. On the other hand, bleached PLFE additive increased the Maximum Dry Density (MDD) of the sample with a decreased Optimum Moisture Content (OMC). The specimen from the bleached PLFE showed that the higher the additives, the better the compaction of the soil. It also exhibited that the 12% additives of boiled and bleached PLFE displayed an increase in Maximum Dry Density (MDD) with a decreased Optimum Moisture Content (OMC) showing better compaction on the soil. The Maximum Dry Density (MDD) for the boiled PLFE is 1536 kg/m³, with an

Optimum Moisture Content (OMC) of 21.1%, while the bleached PLFE has an MDD of 1554 kg/m³ and an OMC of 20.6%.

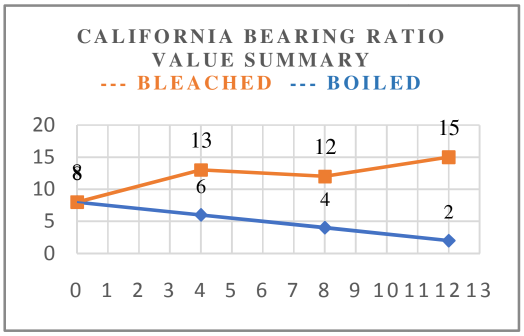

Fig. 3. California Bearing Ration Value Summary

Figure 3 summarizes the CBR values for each specimen. The CBR value for the control sample is 8%. Following the addition of boiled PLFE, the CBR values decreased to 6% for 4% PLFE, 4% for 8% PLFE, and 2% for 12% PLFE, representing a reduction of almost 75% compared to the control sample. On the other hand, the CBR value for the control sample is 8%. Following the addition of bleached PLFE, the CBR values increased to 13% for 4% PLFE, 12% for 8% PLFE, and 15% for 12% PLFE, representing an increase of almost 46.67% compared to the control sample.

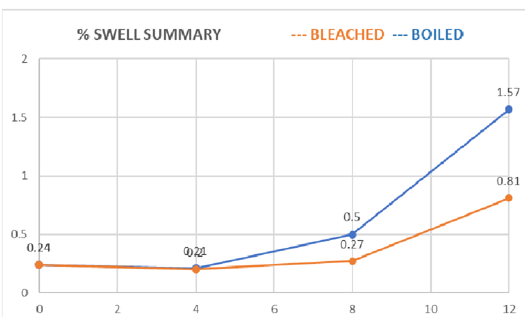

Fig. 4. Percent Swell Summary

Figure 4 presents a summary of the percent swell for each specimen. For boiled PLFE, the swell decreases from 0.24% to 0.21% in the second specimen. However, in the third and fourth specimens, the swell increases to 0.5% with 8% boiled PLFE and significantly rises to 1.57%, nearly five times higher than the control sample. For the bleached PLFE, the swell decreases from 0.24% to 0.20% in the second specimen. In the third and fourth specimens, the swell increases to 0.27% with 8% bleached PLFE and significantly rises to 0.81%, nearly 70% higher than the control sample. However, all the percent swell values fall under a low degree of expansion.All paragraphs must be indented. All paragraphs must be justified, i.e. both left-justified and right-justified.

IV. CONCLUSIONS

The ability of clay minerals to interact with liquids primarily influences the liquid limit and plasticity index of soil [24]. In relation, before conducting the Atterberg Limit Test, the researchers assumed that the soil obtained 2.0 to 3.5 meters below the ground surface at Sta. Ines, Bacolor, Pampanga, would exhibit Atterberg values. This assumption was based on finding a clay-like portion of the soil during the process of sieve analysis. However, during the experiment conducted at DPWH, the soil used was identified as silty soil. According to the study by Bahadori et al., silty soil typically has a plasticity index of less than 5% and is classified as non-plastic soil. [25].

In the results for SPT for loamy/silty soils, typical dry densities usually range from about 1.1 to 1.6 g/cm³ (1100 to 1600 kg/m³) and sandy soils typically retain around 15% to 25% of volumetric soil moisture content at field capacity [26]. This range accounts for variations in organic content, mineral makeup, and compaction levels. A dry density of 1554 kg/m³ and a moisture content of 20.6% which is the highest dry density and lowest moisture content that 12% bleached PLFE reached and falls at the higher end of this spectrum but is still within a plausible range for loamy/silty soil and the moisture content also falls within the standard range. Moreover, it is important to consider the specific needs of your project or application when evaluating whether this density and moisture content is appropriate. Furthermore, both the experiment on boiled PLFE and bleached PLFE additives suggest that a 12% mixture showed a slight improvement in soil compaction, as evidenced by the increased Maximum Dry Density (MDD) and decreased Optimum Moisture Content (OMC). Comparing the two methods bleached PLFE demonstrated higher and better improvement than boiled PLFE.

As for the California Bearing Ratio Test, the addition of boiled PLFE led to a decrease in CBR value. The fiber possibly attributed to alterations in soil structure weakening the soil's mechanical properties and reducing its bearing ratio capacity [27]. Additionally, poor mixing or incompatible additives may cause localized variations in soil strength, further contributing to the observed decrease in CBR values. Moreover, fine-grained soils like silty soils typically have CBR values ranging from 5% to 15% [28], contrasting with the acquired CBR values for boiled PLFE, which were 8% PLFE and 12% PLFE, failing to meet the standard. On the other hand, bleached PLFE yielded better results compared to boiled PLFE, consistently increasing from the control sample up to the 12% bleached PLFE, with all CBR values meeting the standard values for silty soil. The increase in CBR value following the addition of additives is credited to enhanced soil structure and optimized moisture content, both of which improve the soil's load-bearing capacity. Furthermore, additives may enhance soil strength and alter particle size distribution, thus further enhancing CBR values. Additionally, the classification of percent swell is as follows: less than 3% is considered low, 3% to 6% is medium, 6% to 9% is high, and greater than 9% indicates a very high degree of expansion [29]. Based on the experiment both boiled and bleached PLFE contributed to an increase in percent swelling in each specimen, yet remained within the classification of a low degree of expansion. This indicates that these substances have altered the soil's characteristics, improving its ability to absorb and retain water, possibly due to changes in soil structure, enhanced water retention capabilities, or adjustments to particle size distribution induced by the additives. However, when comparing boiled and bleached PLFE, it is observed that bleached PLFE has a lower percent swell, indicating that it does not contribute to the possible entry of water into the pores, which causes swelling of the soil volume.

In conclusion, soil treated with boiled Pineapple Leaf Fiber Extract improves soil compaction but decreases California Bearing Ratio values, whereas bleached Pineapple Leaf Fiber Extract effectively enhances soil parameters in both Standard Proctor and California Bearing Ratio tests. Thus, soil treated with bleached Pineapple Leaf Fiber Extract demonstrated better results in both experiments conducted.

REFERENCES

[1] **J. Dumaop**, "Land Use and Physical Development," 2021, Accessed: Nov. 29, 2023. [Online]. Available: https://www.scribd.com/document/535278553/aep-c7

[2] **N. Huvaj and E. Uyeturk**, "Effects of drying on Atterberg limits of pyroclastic soils of Northern Turkey," Appl Clay Sci, vol. 162, pp. 46–56, Sep. 2018, doi: 10.1016/j.clay.2018.05.020.

[3] **A. A. Firoozi, C. Guney Olgun, A. A. Firoozi, and M. S. Baghini**, "Fundamentals of soil stabilization," International Journal of Geo-Engineering, vol. 8, no. 1, Dec. 2017, doi: 10.1186/s40703-017-0064-9.

[4] **G. P. Makusa**, "STATE OF THE ART REVIEW SOIL STABILIZATION METHODS AND MATERIALS IN ENGINEERING PRACTICE.". Available:https://www.academia.edu/30612927/STATE_OF_THE_ART_REVIEW_SOIL_STABILIZATION_METHODS_AND_MATERIALS_IN_ENGINEERING_PRACTICE

[5] **M. Syduzzaman, M. A. Al Faruque, K. Bilisik, and M. Naebe**, "Plant-based natural fibre reinforced composites: A review on fabrication, properties and applications," Coatings, vol. 10, no. 10. MDPI AG, pp. 1–34, Oct. 01, 2020. doi: 10.3390/coatings10100973.

[6] **M. Asim et al.**, "A review on pineapple leaves fibre and its composites," International Journal of Polymer Science, vol. 2015. Hindawi Limited, 2015. doi: 10.1155/2015/950567.

[7] **K. M. Natarajan, E. T. Samulski, and R. I. Cukie**, "Soil_stabilisation_by_cellulose_xanthate", Accessed: Dec. 03, 2023. [Online]. Available: file:///C:/Users/ADMIN/Desktop/New%20folder/Soil_stabilisation_by_cellulose_xanthate.pdf

[8] **A. A. Langroudi, H. Abdalla, E. R. Sujatha, and G. Kannan**, "An Investigation on the Potential of Cellulose for Soil Stabilization," 2022, doi: 10.3390/su.

[9] **W. M. Hikal et al.**, "Pineapple (<i>Ananascomosus</i> L. Merr.), Waste Streams, Characterisation and Valorisation: An Overview," Open J Ecol, vol. 11, no. 09, pp. 610–634, 2021, doi: 10.4236/oje.2021.119039.

[10] **H. Y. Ch'ng, O. H. Ahmed, S. Kassim, and N. M. A. Majid**, "Co-composting of pineapple leaves and chicken manure slurry," International Journal of Recycling of Organic Waste in Agriculture, vol. 2, no. 1, Dec. 2013, doi: 10.1186/2251-7715-2-23.

[11] **S. A. Khanday, M. Hussain, and A. K. Das**, "A Review on Chemical Stabilization of Peat," Geotechnical and Geological Engineering, vol. 39, no. 8. Springer Science and Business Media Deutschland GmbH, pp. 5429–5443, Dec. 01, 2021. doi: 10.1007/s10706-021-01857-1.

[12] **S. Jose, R. Salim, and L. Ammayappan**, "An Overview on Production, Properties, and Value Addition of Pineapple Leaf Fibers (PALF)," Journal of Natural Fibers, vol. 13, no. 3. Taylor and Francis Inc., pp. 362–373, May 03, 2016. doi: 10.1080/15440478.2015.1029194.

[13] **S. Kaewpirom and C. Worrarat**, "Preparation and properties of pineapple leaf fiber reinforced poly(lactic acid) green composites," Fibers and Polymers, vol. 15, no. 7, pp. 1469–1477, 2014, doi: 10.1007/s12221-014-1469-0.

[14] **Fitriani, N. A. S. Aprilia, and N. Arahman**, "Properties of nanocrystalline cellulose from pineapple crown leaf waste," in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Apr. 2020. doi: 10.1088/1757-899X/796/1/012007.

[15] **I. M. Fareez, N. A. Ibrahim, W. M. H. Wan Yaacob, N. A. Mamat Razali, A. H. Jasni, and F. Abdul Aziz**, "Characteristics of cellulose extracted from Josapine pineapple leaf fibre after alkali treatment followed by extensive bleaching," Cellulose, vol. 25, no. 8, pp. 4407–4421, Aug. 2018, doi: 10.1007/s10570-018-1878-0.

[16] **Nuboer J.**, "Soil texture's influence on water capillary function," Nov. 17, 2023. Available:https://www.sensoterra.com/news/soil-texture-influence-on-water-capillary-function/

[17] **S. Gnanasekaran, S. N. N. Muslih, J. H. Shariffuddin, and N. I. A. A. Nordin**, "Effect of steam and bleaching treatment on the characteristics of pineapple leaves fibre derived cellulose," Pertanika J Sci Technol, vol. 28, no. Special Issue 2, pp. 135–148, 2020, doi: 10.47836/pjst.28.S2.11.

[18] **T. E. Motaung and A. Mtibe**, "Alkali Treatment and Cellulose Nanowhiskers Extracted from Maize Stalk Residues," Materials Sciences and Applications, vol. 06, no. 11, pp. 1022–1032, 2015, doi: 10.4236/msa.2015.611102.

[19] **A. Ariffin and Y. Yusof**, "Effect of Extraction Process and Surface Treatment on the mechanical properties in Pineapple Leaf Fibre," in MATEC Web of Conferences, EDP Sciences, Nov. 2017. doi: 10.1051/matecconf/201713500042.

[20] **W. A. Laftah and W. A. W. Abdul Rahaman**, "Chemical pulping of waste pineapple leaves fiber for kraft paper production," Journal of Materials Research and Technology, vol. 4, no. 3, pp. 254–261, Jul. 2015, doi: 10.1016/j.jmrt.2014.12.006.

[21] **X. Yang et al**., "Characteristics and Functional Application of Cellulose Fibers Extracted from Cow Dung Wastes," Materials, vol. 16, no. 2, Jan. 2023, doi: 10.3390/ma16020648.

[22] **Indian Institute of Techonology Gandhinagar**. "Plastic Limit Test". Department of Civil Engineering, Soil Mechanics Laboratory. IS: 2720 (Part 5) – 1985 (Reaffirmed-2006). Available: https://research.iitgn.ac.in/stl/wp/wp-content/uploads/2022/07/Plastic-Limit-Test.pdf

[23] **GWoei, H. (2017**). PLASTIC LIMIT AND LIQUID LIMIT TEST. Polisas. Available:https://www.academia.edu/33169287/PLASTIC_LIMIT_AND_LIQUID_LIMIT_TEST?fbclid=IwZXh0bgNhZW0CMTAAAR1Ut5mleItk4AaeapD6E9ygdqd2L5rD-Gm0PIv61iB5M4KKSQ7wyKHWjmk_aem_Abwl0aivRv7tDA4uB3AGqLiFd98JzeWUi7U7lmY2TKtHHGyX1Cig2Au8b25ysG5-BMmIPGRVDJuwqI2tRv3p56xi

[24] **R. M. Schmitz, C. Schroeder, and R. Charlier**, "Chemo-mechanical interactions in clay: A correlation between clay mineralogy and Atterberg limits," Appl Clay Sci, vol. 26, no. 1-4 SPEC. ISS., pp. 351–358, Aug. 2004, doi: 10.1016/j.clay.2003.12.015.

[25] **Bahadori, H., Ghalandarzadeh, A., &Towhata, I.** (2008). EFFECT OF NON-PLASTIC SILT ON THE ANISOTROPIC BEHAVIOR OF SAND. SOILS AND FOUNDATIONS, 48(4), 531–545. https://doi.org/10.3208/sandf.48.531

[26] **Certified Crop Advisor study resources (Northeast region)**. (2010). Available:https://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php#:~:text=The%20volumetric%20soil%20moisture%20content,to%2055%25%20for%20clay%20soils

[27] **R. Nini**, "Effect of soil loading surcharge on its CBR value," in World Congress on Civil, Structural, and Environmental Engineering, Avestia Publishing, 2018. doi: 10.11159/icgre18.124.

[28] **Jones, J**. (2022, June 22). California bearing ratio typical values - CBR Testing UK. CBR Testing UK - Nationwide CBR Testing Service. Available:https://www.cbrtesting.com/california-bearing-ratio-typical-values/

[29] **P. J. Thomas, J. C. Baker, and L. W. Zelazny**, "An Expansive Soil Index for Predicting Shrink–Swell Potential," Soil Science Society of America Journal, vol. 64, no. 1, pp. 268–274, Jan. 2000, doi: 10.2136/sssaj2000.641268x

