International Journal of GEOMATE
(Geotechnique, Construction Materials and Environment)
ISSN: 2186-2982 (P), 2186-2990 (O), Japan

Vol. 31, Issue 144, August, 2026, pp.200-207; DOI: 10.21660/2026.144.g15245

INFLUENCE OF BIOCHAR WATER HYACINTH ON THE SHEAR STRENGTH OF ULTISOLS

* Erica Elice S. Uy[1], Jeann Patrick B. Barcelona[2], Juan Angelo V. Malaca[2], Lance Matthew R. Santiago[2], Jose Gabriel R. Zamora[2] and Angelo B. Edora[3]

[1]Faculty, De La Salle University, Philippines; [2,] De La Salle University, Philippines; [3]Nagoya University, Japan

*Corresponding Author, Received: 30 May 2025, Revised: 18 May 2026, Accepted: 25 May 2026

ABSTRACT: Ultisols are reddish, acidic and clayey soils which are abundant in the Philippines. It is commonly found in upland areas and approximately covers 41.5% of the land area. However, this material is underutilized due to its high plasticity which can have an adverse effect to its shear strength. In order to explore ultisol's potential, soil stabilization is essential. A promising material that can be blended to ultisol is water hyacinth biochar. This type of material has hydrophobic qualities which can be beneficial to high plastic material since it can repel water. Water hyacinth was used since it is an invasive species that disrupts the bodies of water that it grows on. In this study, biochar water hyacinth was blended to ultisols having 0%, 5% and 10% proportions. To investigate on the influence of this material to ultisols the relative density was varied. The samples were prepared having a relative density of 32.5%, 60% and 92.5%. The shear strength parameters were established by performing a direct shear test under undrained condition. Based on the results, biochar water hyacinth had a significant effect on the cohesion of the soil.

Keywords: Water hyacinth Biochar, Ultisols, Shear strength, Undrained Condition

1. INTRODUCTION

According to the Bureau of Soils and Water Management (BSWM), one of the most common lowland soil in the Philippines is Ultisols or Alisols. The area covered by Ultisols in the Philippines is approximately 41.5% [1]. They are formed as a result of very extensive weathering and leaching processes that produce a subsurface that is clay-enriched and predominantly composed of minerals including quartz, kaolinite and iron oxides. Ultisols are usually composed of sand, silt and clay [2-5]. The percentage varies due to the lithology and morphology on where it is located and formed. In the Philippine setting, it was found that some Ultisols in the Visayas group of island was observed to have high clay content and high plasticity [5]. Although this soil is abundant in the Philippines, it is not being utilized as a construction material. A possible reason is the high fines content which can have a negative impact to the shear strength. With this, there is a need to explore soil stabilization techniques that will lessen the plasticity and increase the shear strength.

Soil stabilization in general are techniques to improve the index properties, shear strength and compressibility of a soil. It can be categorized into mechanical, physical and chemical stabilization [6, 7]. In mechanical stabilization, it physically alters the soil properties to improve the strength. One way is by adding and blending industrial waste materials such as silica fume, rice husk ash and ground granulated blast furnace slag [8, 9]. These waste materials may improve the gradation of the soil and can also contribute to an increase in shear strength. Mechanical stabilization also involves changing the density of the soil by means of compaction [6, Rivera-7]. In this manner, the void spaces become smaller making the relative density higher. Physical stabilization improves soil's properties by introducing reinforcements such as geotextiles [10, 11]. Chemical stabilization alters the soil's properties by introducing additives such as lime, fly ash and cement. This results to the chemical reactions that enhances the bonding and interlocking in the soil matrix [12]. Also, in this technique the purpose of the additives is to develop pozzolanic reaction which improves the shear strength of a weak soil. The additives are also known as binders which also frequently adopted in the enhancement of particle bonds and interaction. Binders such as lime and cement are very common. However, these materials usually have negative impact to the environment. For lime binders, are calcium-based and undergoes calcination process. This process needs high energy which leads to an increase in carbon dioxide emission [10, 13, 14].

An emerging material for soil stabilization is the use of biochar. This material is a form of charcoal that is both environmentally safe and a stable, carbon-rich form of charcoal that can be added to the soil. This is produced using a process called pyrolysis, where biomass is heated at temperatures starting at 250 Degrees Celsius with almost no oxygen [15]. Waste materials such as agricultural waste, forestry waste, sewage waste and municipal waste are some of the commonly used raw materials [16].

Several studies explored the potential of biochar as an additive to improve the shear strength of soil. In a study by Reddy [17], they used wood biochar in assessing the shear strength of the clay soil mixed with the sample. The biochar proportion used in the study is 5%, 10% and 20%. Based on the results, shear strength increased as the amount of biochar was increased. The study by Xu [18] used what straw as the raw material for biochar. In this study, 0, 2.5, 5, 10, and 20% of biochar by weight was added to the clay. It was observed that the shear strength increased for 2.5 and 5% biochar while 10% and 20% decreased. The largest shear strength was observed at 5% biochar content. Li [19] investigated the effect of the bagasse biochar and rice platycodon biochar to the shear strength of red loam. The proportions of the two biochar were 0%, 2%, 4%, 6%, and 8%. They were added to the loam mass with respect to the dry mass. In their results, the biochar content of 2%, 4% and 6% showed an increase. The largest shear strength was observed at 6% and decrease was observed at 8%. It can be observed that although adding biochar can increase the shear strength at 5% and 6% showed the largest improvement. Also, when the amount of biochar was increased larger than 5% or 6% shear strength decreased. However, comparing it to 0% biochar, there was still an improvement observed.

A potential biochar raw material is water hyacinth. According to Dersseh [20], water hyacinths are invasive tracheophyte plant. Several countries experienced disruption due to its abundance. In the Philippines, thick water hyacinth beds cover the rivers which can obstruct the passageway of barges and ferry services [21]. The potential of water hyacinth as an additive was explored by numerous studies. A study by Sathya [22] assessed the influence of water hyacinth extract from Thanjavur District, India as a Bio-admixture in cement and concrete. It was found that there is a progressive increase of compressive strength whenever there is an increase in the replacement of water hyacinth extract. In the study of Okwadha & Makomele [23], the water hyacinth extract served as an admixture in concrete cube production. The ratios of water hyacinth used were 0%, 10%, 15%, 20%, and 25%. Slump tests and compressive tests of various concrete cubes were performed to evaluate the workability of the concrete after 7, 14 and 28 days. After all the laboratory tests, the researchers concluded that the water hyacinth in the form of liquid extract increased the workability of concrete with an increase in percentage replacement of concentration of the solution. The enhancement of workability in concrete may be caused by the small fragments of lignocellulose and hemicellulose dissolved in water hyacinth extract.

Accordingly, this study aims to explore the potential and effect of water hyacinth biochar (WHBC) to the shear strength of Ultisols. Biochar was added by weight and the proportions were 0%, 5%, and 10%. The relative density of the soil sample was varied to further assess the effectiveness of the water hyacinth biochar in increasing the shear strength of soil. The relative densities used were 32.5% (Loose), 60% (Medium Dense), and 92.5% (Very Dense). Direct shear test was performed simulating an undrained condition.

2. RESEARCH SIGNIFICANCE

This study investigated the effect of water hyacinth biochar's on the shear strength of Ultisols. The significance of the study is in the potential of treated Ultisols as a construction material. The results of the study highlight the contribution of water hyacinth biochar to the shear strength of Ultisols and the potential of WHBC as an additive for soil amendment. Lastly, the study introduces another beneficial use of water hyacinth. This can lessen its negative impact to the water ways by processing it into a potential additive for soil stabilization.

3. ULTISOL

The samples were obtained from the mountainous are of Zamboanga Peninsula region in Mindanao. Based on visual inspection in accordance with Standard Practice for Description and Identification of Soils, the sample has a reddish color and has a flat particle shape as shown in Fig.1. When the cementation was observed, it is considered moderate since the particles crumbled with a considerable amount of pressure. For its structure, it is deemed homogeneous. It was observed that it has the same color and appearance throughout.

3.1 Index Properties

Sieve and Hydrometer Analysis and Index

properties such as specific gravity (G_s), liquid limit (LL), plastic limit (PL), plasticity index (PI), maximum dry unit weight (γ_{dmax}), optimum moisture content (OMC), minimum void ratio (e_{min}) and maximum void ratio (e_{max}) were established. Soil classification was established considering the Unified Soil Classification System (USCS). The experiments were performed in accordance to American Society for Testing and Materials (ASTM) Standards. The results are tabulated in Table 1.

Fig.1. Ultisols Soil

Table 1. Index Properties of Ultisols

Index Properties	
G_s	2.78
LL	51
PL	39
PI	12
γ_{dmax} (kN/m^3)	12.66
OMC	36.64%
e_{min}	1.537
e_{max}	1.930

The Grain Size Distribution Curve (GSDC) is shown in Fig.2. Based on the trend of the GSDC, it shows a poorly graded sample and its soil classification is SC (clayey sands, sand-clay mixtures). Scanning electron microscopy (SEM) of the Ultisols is shown in Fig.3. It can be observed that the texture is irregular, angular grains with rough surfaces. It can also be observed that there is a presence of agglomeration which is the result of active surface interaction. The Energy-dispersive X-ray spectroscopy (EDX) of Ultisol is tabulated in Table 2. Based on the results, the soil predominantly composed of Carbon and Oxygen. Traces of Aluminum, Silicon and Iron were observed. The EDX was determined to investigate the elements that can have a reaction with the water hyacinth biochar.

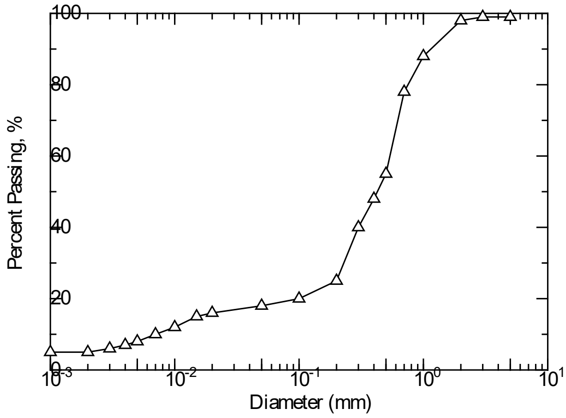

Fig.2. GSDC of Ultisol

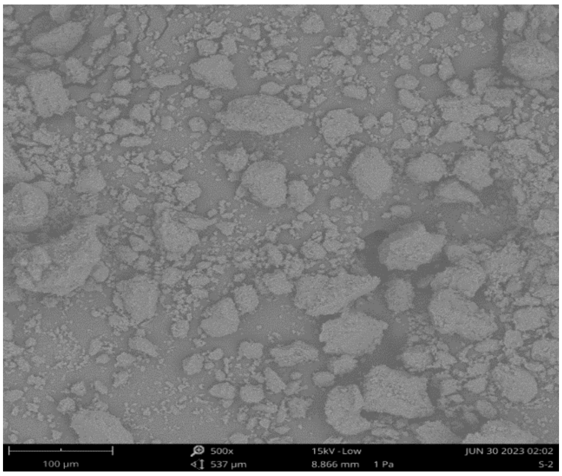

Fig.3. SEM of Ultisols

Table 2. EDX of Ultisol

Element Symbol	Element Name	Atomic Conc.	Atomic Weight
C	Carbon	49.06	43.42
O	Oxygen	37.68	25.04
Al	Aluminum	4.78	7.13
Si	Silicon	3.98	6.18
Fe	Iron	2.17	6.71
Nb	Niobium	1.83	9.40

4. WATER HYACINTH BIOCHAR

The water hyacinth was sourced in the National Capital Region. Shown in Fig.4 is the biochar process implemented in the study. Before the biocharing process, the plant was first sun dried to remove moisture. Once dried, it was cut into smaller pieces in order to fit the furnace. For the biochar process, a furnace was fabricated as shown to accommodate the target temperature conditions.

Fig.4. Biochar Process

According to Masto [24], the optimal temperature and time for water hyacinth biochar process is 300 to 350 Celsius for 30 – 40 minutes, respectively. This condition was chosen since it yielded the optimal temperature for the biochar process while minimizing the increase in pore structure and size of particles. This may decrease the shear strength of amended soil samples in addition to preserving biochar yield.

SEM-EDX of water hyacinth biochar was also obtained. This is to verify the quality of biochar process performed. Based on the results of SEM in Fig.5, it can be seen that the texture is smooth but has cracked surface. Thin layers were also observed and this suggests that there could be weak bonding between internal planes. It is noticeable that its particle size is not uniform. Plate-like or flaky particles were also observed and sheet-like fragments which has a tendency to break along the natural planes. Shown in Table 3 is the summary of results of EDX. Based on the results, Carbon is the predominant material which is an indication of an effective biochar process. Although pyrolysis was achieved, presence of Oxygen was observed. This indicates that the temperature used resulted to a hydrophilic water hyacinth biochar, retaining oxygen-containing functional groups that limited its ability to form strong bonds with the soil matrix. The result is similar to other studies that used low temperatures of 200 to 300 Celsius for pyrolysis [27].

Table 3. EDX of WHBC

Element Symbol	Element Name	Atomic Conc.	Atomic Weight
C	Carbon	72.35	57.60
O	Oxygen	22.20	23.55
Cl	Chlorine	1.46	3.44
K	Potassium	1.40	3.62
Nb	Niobium	1.17	7.18
Ca	Calcium	0.61	1.62

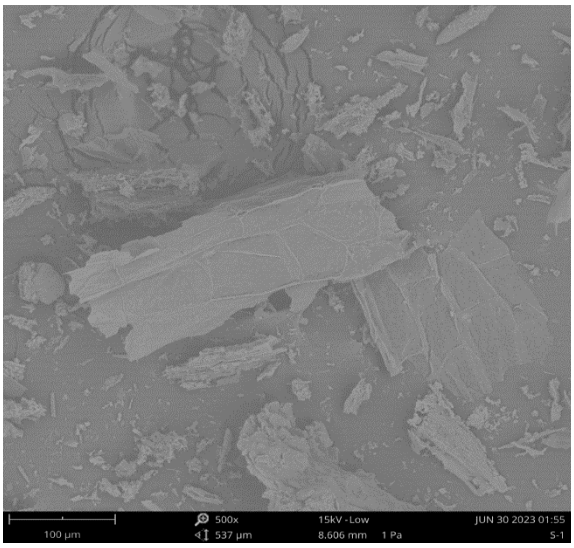

Fig.5. SEM of the WHBC

5. SHEAR STRENGTH TEST AND RESULTS

5.1 Sample Preparation

Remolded samples were tested in this study. The target amount of soil and water for 0% water hyacinth biochar was based on γ_{dmax} and OMC of the Ultisols. The target amount of soil, water and water hyacinth was based also on the γ_{dmax} and OMC of Ultisols mixed with WHBC. To achieve this, a separate standard proctor test was performed considering the target proportions of WHBC. The summary of results is tabulated in Table 4.

Table 4. Percentage of WHBC Amended in relation to the soil's Optimum Moisture Content and Maximum Dry Unit Weight

WHBC Proportions (%)	Optimum Moisture Content (%)	Maximum Dry Unit Weight (kN/m^3)
0	36.64	12.66
5	41.6	6.2
10	47.67	5.63

Three relative densities, 32.5%, 60%, and 92.5%, were prepared to know the effect of WHBC to the shear strength of Ultisols. These values were chosen due to being the median value for the ranges of loose, medium dense, and dense conditions. Once the target amount of soil, water and water hyacinth is established, these were mixed and soaked for at least 16 hours. To create remolded samples, moist tamping was performed. Moist tamping was done to ensure uniform density within the sample [25]. The samples were tamped for a minimum of 10 times per layer for a minimum of 3 layers.

5.2 Direct Shear Test Experimental Design

To evaluate the effectiveness of the WHBC in increasing a soil's shear strength, the shear strength of the soil samples mixed with 0%, 5%, and 10% biochar were determined using a direct shear test based on the ASTM D3080. The test was conducted under drained conditions. The rate of shearing used was 0.12 mm/min [26]. The normal stresses used in the test were 22.5 kPa, 45 kPa, and 90 kPa. These normal stresses simulate a fill with a height of at most 6 m.

5.3 Shear Strength Results

For the direct shear test, typical results of the stress-strain and volumetric strain-shear strain curves are shown in Figs.6-10. For Ultisols, ductile failure was observed for 32.5% relative density in general. For 60% relative density, brittle failure was observed for 22.5 kPa. For 92.5% relative density, brittle failure was observed in general. For samples with water hyacinth biochar, strain hardening was observed for all samples. For the volumetric strain-shear strain curves samples exhibit contractive behavior during shearing. Samples tested in general showed ductile behavior as the mode of failure.

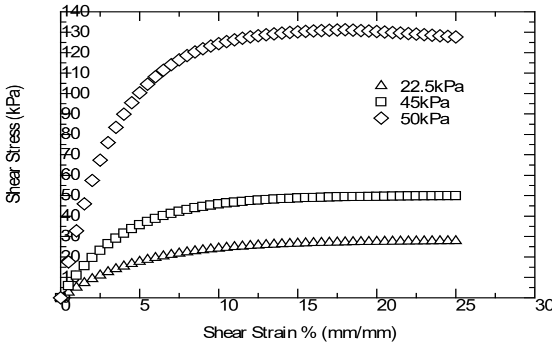

Fig.6. Stress-strain Curve for 32.5 D_r for Ultisols

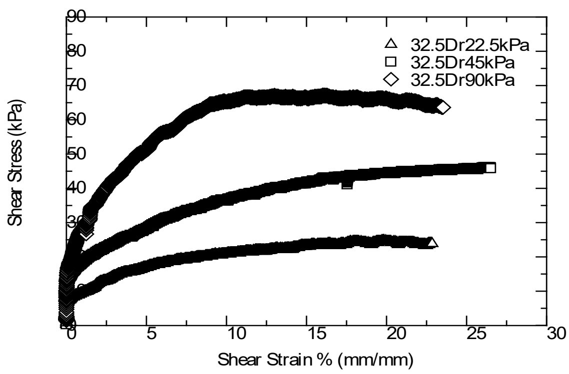

Fig.7. Stress-strain Curve for 32.5 D_r with 5% WHBC

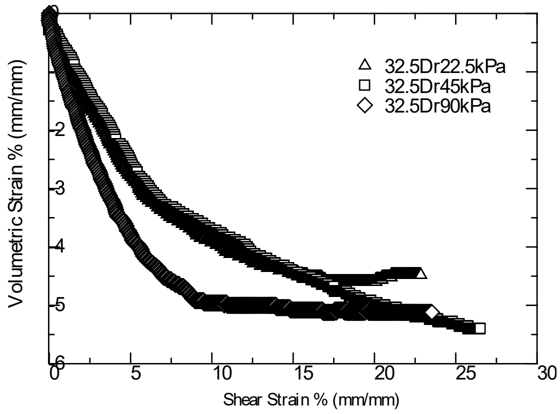

Fig.8. Volumetric strain-shear strain Curve for 32.5 D_r with 5% WHBC

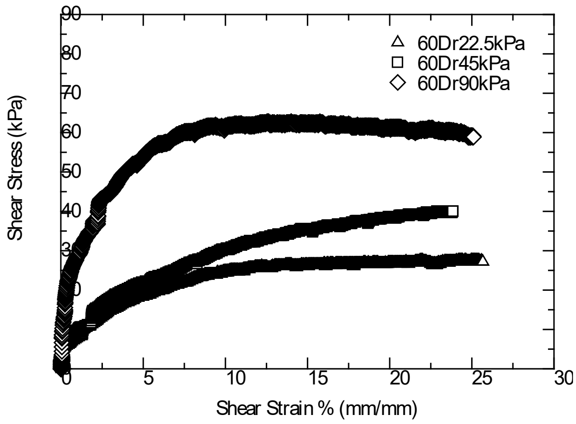

Fig.9. Stress-strain Curve for 60 D_r with 5% WHBC

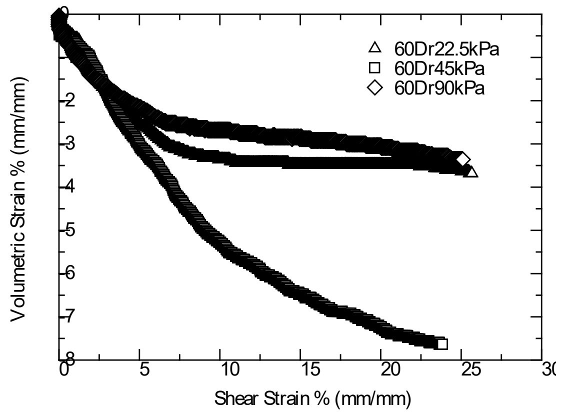

Fig.10. Volumetric strain-shear strain Curve for 60 Dr with 5% WHBC

The Mohr-Coulomb Failure Envelope of each relative density was plotted as shown in Fig.11 and 12. For pure soils, it can be seen that at 92.5 relative density, the failure envelope is less steep, indicating a weaker sample. When comparing different biochar amendments, Fig.12 verifies that increasing the amount of biochar present decreases the cohesion of the soil. This decrease in cohesion confirms that WHBC may not be suitable for increasing the shear strength parameters of the soil sample. This is due to the structure and shape of the WHBC.

The shear strength parameters of the soil sample were obtained and compared with one another, as tabulated in Tables 5 and 6. As seen, there is a decrease in cohesion when WHBC was added to the soil. However, for 60% relative density sample with 5% and 10% WHBC, inconsistent results were observed. This can be due to the uneven distribution of WHBC when the sample was prepared. For the angle of internal friction, no consistent trend was observed. To further analyse the impact of WHBC, the shear strength was determined as shown in Table 7. It can be seen that at 32.5% and 60% relative density, the addition of WHBC did not enhance the bonding and interlocking of the soil particles in Ultisols. This can be attributed to the flaky texture of WHBC, which acted similarly to fine particles, thereby reducing particle contact. In addition, due to the low temperature used in the pyrolysis process, the WHBC resulted in a hydrophilic material. This affected and weakened the development of cohesion, which also contributed to the reduction in shear strength. For 92.5% relative density, the shear strength increased as the amount of WHBC is increased. The tight packing and few void spaces contributed to the increase in shear strength.

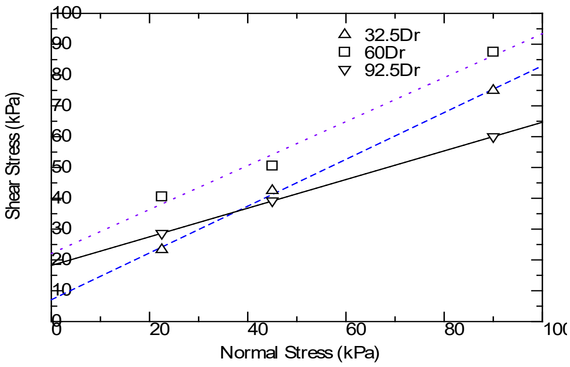

Fig.11. Mohr-Coulomb Failure Envelopes of 0% BC at Different Relative Densities

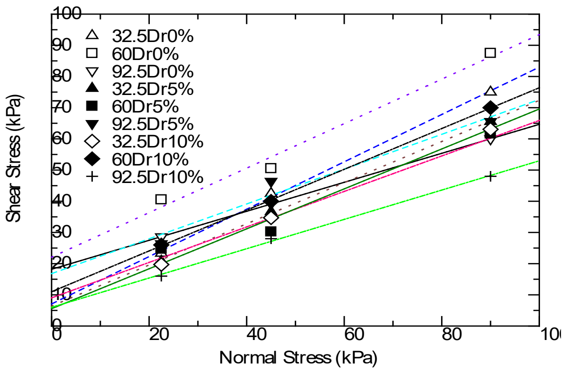

Fig.12. Mohr-Coulomb Failure Envelopes of 0%, 5%, & 10% BC at Different Relative Densities

Table 5. Percentage of WHBC Amended in Relation to the Soil's Cohesion at Different Relative Densities

	Relative Density (%)		
WHBC (%)	32.5	60	92.5
0	8.61	22.08	18.19
5	6.39	0.57	16.81
10	5.56	23.47	14.44

Table 6. Percentage of WHBC Amended in Relation to the Soil's Angle of Internal Friction at Different Relative Densities

	Relative Density (%)		
WHBC (%)	32.5	60	92.5
0	35.40	35.50	24.93
5	33.41	29.63	29.17
10	32.61	15.81	33.48

Table 7. Percentage of WHBC Amended in Relation to the Soil's Shear Strength at Different Relative Densities

	Relative Density (%)		
WHBC (%)	32.5	60	92.5
0	24.60	54.19	60.02
5	21.23	26.16	67.04
10	19.96	36.21	73.97

An Analysis of Variance (ANOVA) was carried out to determine whether the effects of the percentage of the WHBC and its relative density were significant on both the cohesion and angle of internal friction of the soil. In the analysis, the cohesion values of the 60% relative density sample were disregarded due to its low R-squared value from the regression analysis. For the sample's cohesion, the percentage of WHBC and relative density yielded a p-value of 0.02 and 0.002 respectively, which was less than the level of significance of 5%. As such, it can be said that both the amount of biochar and its relative density may have a significant effect on the cohesion of the sample. As for the friction angle, a p-value of 0.38 and 0.25 was obtained for the percentage of WHBC and relative density. This implies that both the relative density and the percentage of biochar may not have a significant effect on this.

6. CONCLUSION

The study explored the potential of Ultisols as a construction material. However, due to its high fines content the soil was improved by adding WHBC. It can be observed that the cohesion decreased as the presence of biochar increased. For the angle of internal friction, no consistent pattern was observed. This is because of the flaky texture of WHBC which behaved similar to a fine grained material. Instead of causing an increase in the cohesion, a reduction was observed since the pyrolysis temperature used made the material hydrophilic which limits formation of strong bonds with the soil. Due to the texture and hydrophilic behavior of WHBC, it is recommended to be used as an additive for the purpose of improving the permeability of a material.

7. ACKNOWLEDGEMENTS

The researchers would like to acknowledge the Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University faculty members, laboratory coordinator, staff and technicians for the support in the research.

8. REFERENCES

1. Rondal J. D., Soil, Water and Climatic Resources of the Philippines: Constraints, Problems and Research Opportunities. JIRCAS International Symposium Proceedings, Vol. 13, 2005, pp. 41–52.
2. Nandi A., and Luffman I., Erosion Related Changes to Physicochemical Properties of Ultisols Distributed on Calcareous Sedimentary Rocks. Journal of Sustainable Development, Vol. 5, No. 8, 2012, pp. 52–60. https://doi.org/10.5539/jsd.v5n8p52.
3. Igwe C. A., Zarei M., and Stahr K., Soil Hydraulic and Physico-Chemical Properties of Ultisols and Inceptisols in South-Eastern Nigeria. Archives of Agronomy and Soil Science, Vol. 59, Issue 4, 2013, pp. 491–504. https://doi.org/10.1080/03650340.2011.649475.
4. Navarrete I. A., Tsutsuki K., Land-use impact on soil carbon, nitrogen, neutral sugar composition and related chemical properties in a degraded Ultisol in Leyte, Philippines. Soil Science and Plant Nutrition, Vol. 54, Issue 3, 2008, pp. 321–331.
5. Piamonte M. K., Asio V. B., Lina S. B., Morpho-physical and chemical characteristics of strongly weathered soils in Silago, Southern Leyte, Philippines. Agricultural and Tropical Research, Vol. 36, Issue 2, 2014. https://doi.org/10.32945/atr3627.2014
6. Hasan M. F. R., Utama I. Z., Razzak A. F. A., Salimah A., and Agung P. A. M., Clayshale Stabilization Using Active Natural Lime to Increase the Shear Strength of Soil. Department of Civil Engineering, Politeknik Negeri Jakarta, 2024.
7. Rivera-Gómez C., and Galán-Marín C., Biodegradable Fiber-Reinforced Polymer Composites for Construction Applications. In: Lau A. K.-t. and Hung A. P.-Y. (Eds.), Natural Fiber-Reinforced Biodegradable and Bioresorbable Polymer Composites, Woodhead Publishing, 2017, pp. 51–72. https://doi.org/10.1016/B978-0-08-100656-6.00004-2.
8. Almuaythir S., Zaini M. S. I., Hasan M., and Hoque M. I., Sustainable Soil Stabilization Using Industrial Waste Ash: Enhancing Expansive Clay Properties. Heliyon, Vol. 10, Issue 20, 2024, Article e39124. https://doi.org/10.1016/j.heliyon.2024.e39124.
9. Setyowati A. S. G., and Raharja I., Utilization of Industrial Waste as Soil Stabilizer to Enhance Direct Shear Strength. Chapter in Biodegradable Fiber-Reinforced Polymer Composites for Construction Applications, 2017.
10. Jawad I. T., Taha M. R., Majeed Z. H., and Khan T. A., Soil Stabilization Using Lime: Advantages, Disadvantages and Proposing a Potential Alternative. Research Journal of Applied Sciences, Engineering and Technology, Vol. 8, 2014, pp. 510–520.
11. Afrin H., A Review on Different Types of Soil Stabilization Techniques. International Journal of Transport Engineering and Technology, Vol. 3, 2017, pp. 19–24.
12. Barman D., and Dash S. K., Stabilization of Expansive Soils Using Chemical Additives: A Review. Journal of Rock Mechanics and Geotechnical Engineering, Vol. 14, Issue 4, 2022, pp. 1319–1342. https://doi.org/10.1016/j.jrmge.2022.02.011.
13. Birchal V. S. S., Rocha S. D. F., Ciminelli V. S. T., The effect of magnesite calcination conditions on magnesia hydration. Mineral Engineering, Vol. 13, Issues 14-15, 2000, pp. 1629–1633.
14. Shand M. A., The Chemistry and Technology of Magnesia. Wiley-Interscience, New York, 2006.
15. Department of Primary Industries and Regional Development, Australia, 2022.
16. Amalina F., Abd Razak A. S., Krishnan S., Sulaiman H., Zularisam A. W., Nasrullah M.,

Biochar production techniques utilizing biomass waste-derived materials and environmental applications – A review. Journal of Hazardous Materials Advances, Vol. 7, August 2022, Article 100134.

17. Reddy K. R., Yaghoubi P., Yukselen-Aksoy Y., Effects of biochar amendment on geotechnical properties of landfill cover soil. Waste Management & Research, Vol. 33, Issue 6, 2015, pp. 524–532. https://doi.org/10.1177/0734242x15580192
18. Xu K., Yang B., Wang J., Wu M., Improvement of Mechanical Properties of Clay in Landfill Lines With Biochar Additive. Arabian Journal of Geosciences, Vol. 13, Issue 13, 2020. https://doi.org/10.1007/s12517-020-05622-1
19. Li K., Xu Y., Tan Y., Cai X., Liu Z., and Xu Q., Research on the Strength Characteristics of Red Soil Amended by Biochar. Sustainability, Vol. 17, Issue 3, 2025, Article 1174. https://doi.org/10.3390/su17031174.
20. Dersseh M. G., Melesse A. M., Tilahun S. A., Abate M., Dagnew D. C., Water hyacinth: Review of its impacts on hydrology and ecosystem services—lessons for management of Lake Tana. Extreme Hydrology and Climate Variability, 2019, pp. 237–251. https://doi.org/10.1016/b978-0-12-815998-9.00019-1
21. Abenoja A. K. R., Cleofe B. I. A., Mondero N. A. R., Rodriguez P. N., and Marcelo J. S., Impacts of the Use of Water Hyacinths as a Form of Livelihood Programs in the Local Residents of Taguig City: Inputs for Tourism Entrepreneurship. International Journal of Tourism and Hospitality, Vol. 1, Issue 4, 2021, pp. 23–29. https://doi.org/10.51483/IJTH.1.4.2021.23-29.
22. Sathya A., et al., Influence of bio admixture on mechanical properties of cement and concrete. Asian Journal of Applied Sciences, Vol. 7, Issue 4, 2014, pp. 205–214.
23. Okwadha G. D. O., Makomele D. M., Evaluation of water hyacinth extract as an admixture in concrete production. Journal of Building Engineering, Vol. 16, 2018, pp. 129–133. https://doi.org/10.1016/j.jobe.2018.01.002
24. Masto R. E., Kumar S., Rout T., Sarkar P., George J., Ram L., Biochar from water hyacinth (Eichornia crassipes) and its impact on soil biological activity. CATENA, Vol. 111, December 2013, pp. 64–71. https://doi.org/10.1016/j.catena.2013.06.025
25. Jagodnik V., Arbanas Ž., Cyclic Behaviour of Uniform Sand in Drained and Undrained Conditions at Low Confining Stress in Small-Scale Landslide Model. Sustainability, Vol. 14, Issue 19, 2022, Article 12797. https://doi.org/10.3390/su141912797
26. Dafalla M. A., Effects of clay and moisture content on direct shear tests for clay-sand mixtures. Advances in Materials Science and Engineering, 2013, pp. 1–8.
27. Fan M., Li C., Shao Y., Zhang S., Gholizadeh M., Hu X. Pyrolysis of cellulose: Correlation of hydrophilicity with evolution of functionality of biochar. Science of The Total Environment, Vol. 825, 2022, Article 153959.https://doi.org/10.1016/j.scitotenv.2022.153959