

Evaluation of some geotechnical properties of clay stabilized with *piliostigma thonningii* pod ash for road filling

Usman, N.

Department of Civil Engineering, Hassan Usman Katsina Polytechnic, Katsina Nigeria

Paper History

Received: 07th Mar, 2023

Accepted: 13th April, 2023

Published: 10th May, 2023

Abstract:

Construction of engineering structures on problematic soils such as clay is difficult and expensive, it sometimes requires hauling of good materials from other sources or the stabilization of in-situ soil to reduce cost. The aim of this paper is to evaluate some geotechnical characteristics of clay soil stabilized with *Piliostigma Thonningii* Pod Ash (PA) for road construction. The *Piliostigma Thonningii* used in this study was obtained from Gwaraje Village, Katsina state Nigeria. The pod was burned in the furnace under a controlled temperature to obtain pod ash (PTA). The percentages of PTA used were 2%, 4%, 6%, 8% and 10%, then Compaction, Atterberg limits, California bearing ratio (CBR) and direct shear tests were conducted on control clay (0% PTA) and PTA stabilized clay. The compaction test result shows an increase in maximum dry density with the increase of PTA percentage, while optimum moisture content remains constant at 4%, 6% and 8% PTA stabilized samples. Generally, CBR, shear strength and bearing capacity were improved with the increment of PTA percentage, the optimum improvement was obtained at 8% PTA stabilized samples. Liquid and plastic limits of the stabilized clay were increased which shows an improved clay strength under moisture, therefore 8% of PTA is the optimum content in stabilizing clay that could be used for effective road fillings.

Corresponding author

Usman, N.

nuragafai@gmail.com

Keywords: Clay, *Piliostigma Thonningii*, bearing capacity, California bearing ratio, stabilization

1. Introduction

Soil stabilization refers to the process in which a cementing or other chemical material is introduced into a natural soil to enhance one or more of its properties. Soil stabilizing additives are used to improve the properties of less-desirable soils [1]. When a stabilizing agent is used, it improves and maintains soil moisture content, increases soil particle cohesion, and serves as cementing and waterproofing agent [2].

Civil engineering works face difficulty when the subgrade is found to be clay or weak soil [3]. Soils having high clay content have to swell when their moisture content is increased [4]. Much research has been done on soil stabilization using various additives; the most common among these additives are cement and lime [5], but in recent years the use of rice husk ash was explored [6]. The high strengths developed by using cement and lime may sometimes not be required [7]. Therefore, there is a need for cheaper additives that can be used to improve the soil's mechanical properties [8].

In other developments, locally produced admixtures are being developed to reduce the use of expensive imported admixtures in concrete such as the effect of locust bean pod powder on the strength properties of concrete and Gum Arabic as an admixture in concrete. Also, the use of *Piliostigma Thonningii* pod powder as an admixture in concrete. Considering the above, it can be seen that most of the research conducted on local additives involved concrete strength improvement. Thus, this paper tends to evaluate some geotechnical characteristics of clay stabilized with *Piliostigma Thonningii* Pod Ash (PTA) for road filling.

2. Materials and methods

2.1 *Piliostigma Thonningii* Pod Ash (PTA)

Piliostigma Thonningii tree is found in many places in West Africa, it is a leguminous plant belonging to the family of Caesalpiniaceae, a family that comprises trees, shrubs, or very rarely scramblers [9]. The tree is perennial in nature and its petals are white to pinkish color produced between November and April [10 – 12]. While the fruits, which is a hairy, hard, flattish pod that turns rusty brown, woody, and twisted which splits at ripening and usually persistent on the tree are produced between June and September [13]. It is found growing abundantly as a wild uncultivated tree in many parts of Nigeria such as Zaria, Bauchi, Ilorin, Plateau, Lagos, and Abeokuta [14]. The local builders use the pod powder as strength improving agent in mud for walling and rendering. The chemical composition of *Piliostigma Thonningii* pod ash is presented in Table 1. It cost about \$0.06 per kg which made it cheaper than any locally available material of its kind.

The presence of SiO₂, Al₂SO₃, Fe₂O₃ and CaO in *Piliostigma Thonningii* pod ash signifies its ability to stabilize soils. When the above compounds are blended with soil in the presence of water, a set of reactions occur resulting in the formation of cementitious and pozzolanic gels [calcium silicate hydrate gel (CSH) and calcium aluminate silicate hydrate gel (CASH)]. These reactions contribute to soil stabilization by binding the solid particles together, and this binding produces a stronger soil matrix [16].

Table 1: Chemical Composition of PTA [13]

Compound	%
SiO ₂	3.8
Al ₂ SO ₃	9.5
Fe ₂ O ₃	35.7
CaO	1.5
MgO	1.96
K ₂ O	25.03
NaO ₂	1.75
SO ₂	1.17
LOI	3.8

2.2 Clay

The soil used in this research is classified as CL (lean clay) based on the Unified Soil Classification System (USCS) as described in ASTM D2487-17, it was obtained from Gwaraje village in Katsina, northern Nigeria. A disturbed sampling method was adopted, the soil sample was collected at a depth of 1m, and packed in plastic bags to avoid loss of moisture during transportation to the laboratory. After the determination of natural moisture content, the sample was air-dried. Table 2 shows some of the index properties of natural soil without the addition of PTA using the relevant tests in accordance with ASTM standards.

From Table 2, the strength of the clay used for this study is very low considering the shear strength, bearing capacity, and California bearing ratio.

2.3 Methodology

To study the effect of *Piliostigma Thonningii* pod ash (PTA) on clay stabilization, the following tests were conducted on the natural clay as a control and a mixture of natural clay with 4%,

6%, 8% and 10% PTA. Liquid limit, plastic limit, and Modified proctor compaction tests were first observed, followed by California bearing ratio (CBR) and shear box test at the determined optimum moisture content of each percentage of PTA added. The CBR test was conducted on un-soaked samples.

Table 2: Properties of the clay used in this research.

Test Observed	Values Obtained
Liquid Limit	29%
Plastic Limit	17%
Plasticity Index	12%
Linear Shrinkage	5%
Natural moisture content	23%
Optimum Moisture Content (OMC)	12.50%
Max. Dry Density (MDD)	1400kg/m ³
Unified Soil Classification System	CL
Color	Grayish Black
Specific Gravity	2.69
Cohesion (c)	2.5
Angle of Internal Friction (θ)	11°
Shear Strength	10 kN/m ²
Soil Bearing Capacity	49kN/m ²
California Bearing Ratio (Unsoaked)	15%

3. Result and discussion

3.1 Compaction test

A modified compaction test was performed in accordance with ASTM D1557-12 on the natural clay sample and other four stabilized samples (i.e. 4%, 6%, 8% and 10% PTA samples). The result of optimum moisture content is summarized in Figure 1 and the result of maximum dry density is illustrated in Figure 2.

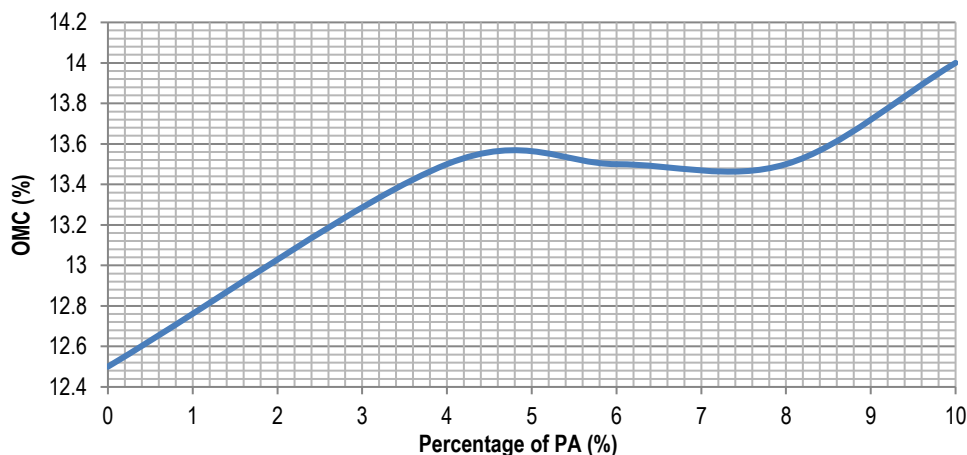


Fig. 1: Variation of Optimum Moisture Content with % PTA.

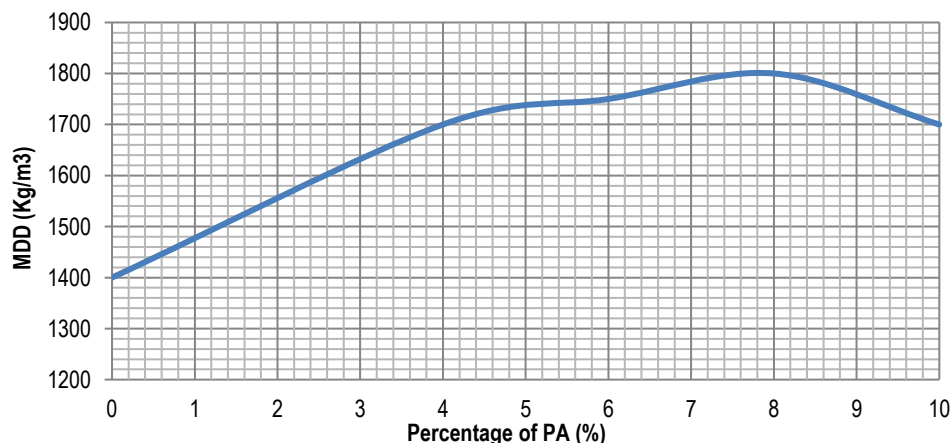


Fig. 2: Variation of Maximum Dry Density (MDD) with % PTA

From Figures 1 and 2, the maximum dry density (MDD) increases with the increment of PTA from 0% to 8% while the optimum moisture content remains constant at 4% to 8%. At 10% PTA maximum dry density decreased while optimum moisture content increased. The increment of clay-PTA mixture MDD at 4%, 6%, and 8% is due to the improved expansion behavior of the stabilized clay at the above range of PTA percentages. In regard to steady OMC from 4% to 8% PTA, this is due to the ability of the PTA to control the MDD of the clay at 13.5% moisture content as indicated by the compaction test. In the case of a 10% soil-PTA mixture, the decrease in the MDD is attributed to the replacement of soil by the PTA and acts as a filler in the mixture which has a relatively lower specific gravity of 2.52 compared to that of the soil which is 2.69.

3.2 Atterberg limits

The liquid limit test was conducted using the Casagrande apparatus according to ASTM D4318-17. The plastic limit test was also conducted according to the ASTM D4318-17. These tests were carried out to investigate the effect of PTA on the consistency limits. Table 3 shows the summary of Atterberg limits.

Table 3: Atterberg limits of natural and stabilized soil.

Soil Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0% PTA	29	17	12
4% PTA	32	19	13
6% PTA	32	19	13
8% PTA	31	19	12
10% PTA	30	18	12

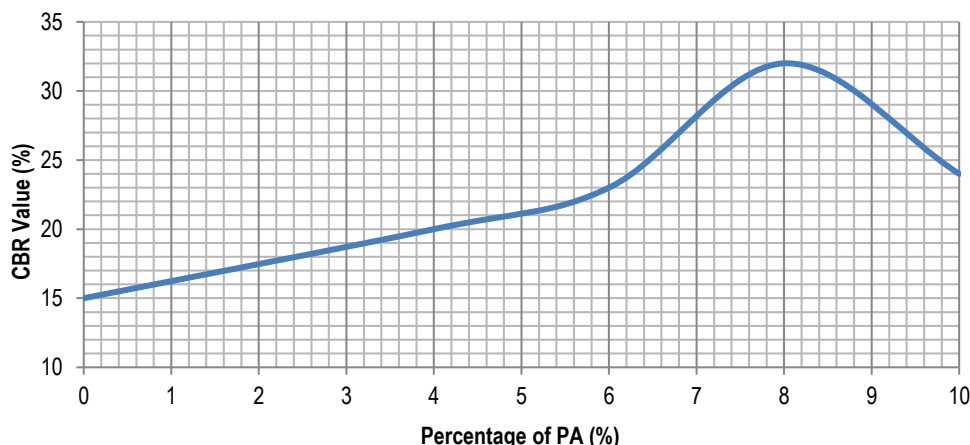


Fig. 3 Variation of CBR value with % PTA content.

3.4 Direct shear test

The shear box test was conducted in accordance with ASTM D3080-11, although this method is widely used to test cohesion-less soils but it can be applied to test cohesive soils under the condition of drained loading to derive drained shear strength parameters [19]. Shear strength parameters were determined from the result of the shear box test, the test was conducted at the optimum moisture content of un-stabilized clay and at each percentage of PTA added to the clay. The result is summarized in Table 3 shown below.

From Table 3, the constant cohesion of stabilized clay from 4% to 8% is greater than that of the original soil, this is as a result of the binding ability of the stabilizing agent (i.e. PTA) to hold the soil particles together, but dropped at 10% which is due to the excess PTA that could not react with the clay minerals and remain as coatings on the clay particles. The increment of shear strength with the increment of PTA percentage shows a good

characteristic of the PTA stabilizer which could improve clay shear strength by 30% [20].

3.3 California bearing ratio (CBR) Test

The California bearing ratio (CBR) value is a tool used to indicate the soil strength, it also sheds more light on the bearing capacity of soil stratum. CBR value is also used in the design of base and sub-base of pavements. The test was conducted according to ASTM D1883-16. The CBR value of un-stabilized clay was found to be 15%, Figure 3 shows CBR values of natural and PTA stabilized soil at different percentages. Generally, CBR values increased with the increment of PTA content. A peak CBR value of 32% was recorded for 8% treatment, and dropped to 24% at 10% PTA content. This shows that there is a formation of cementitious materials due to the reaction between the PTA constituents (Al_2SO_3 , Fe_2O_3 and SiO_2) and clay minerals [18]. At 10%, the stiffness of the soil mixture has been affected by additional PTA which coats soil particles and tends to disintegrate the particles hence reducing the CBR value. Basically, the CBR value has been improved from 15% to 32%.

Table 3 Shear strength parameters (Natural & PA stabilized soil)

Soil Sample	Cohesion value c	Angle of Internal Friction	Shear Strength (kN/m ²)
0% PTA	2.5	11°	10
4% PTA	3.75	11°	11.66
6% PTA	3.75	12°	12.22
8% PTA	3.75	14°	12.78
10% PTA	3.5	11°	11.38

3.5 Bearing capacity

The bearing capacity of the natural and PTA-stabilized clay was determined using shear strength parameters. The result is described in Figure 4 below.

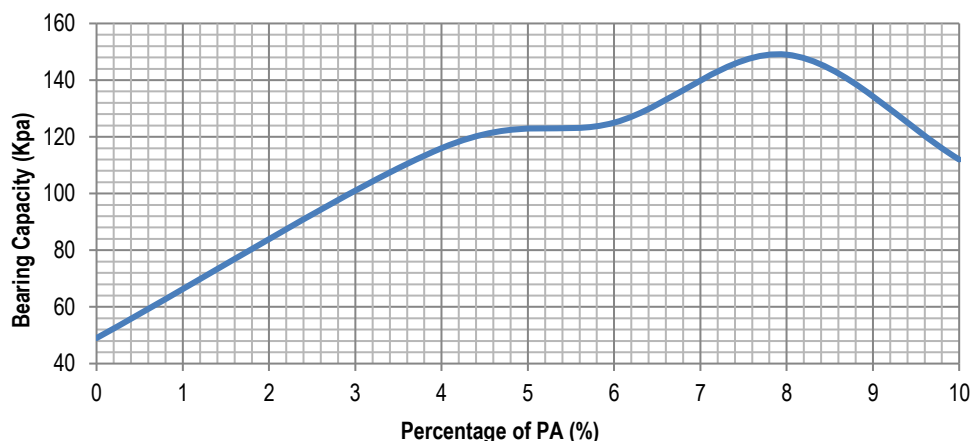


Fig. 4 Bearing capacity of natural and PTA stabilized soil.

From Figure 4, the bearing capacity of the natural clay has been improved to 300%. This is the function of shear strength improvement by the PTA stabilizer.

3.6 Unconfined compressive strength (UCS)

An unconfined compressive strength test was conducted in accordance with ASTM D2166-16. The test was conducted on natural clay and PTA-treated clay. The test specimens were

averagely 76 mm height and 38 mm diameter. Figure 5 is an illustration of result obtained from the UCS test. From Figure 5, the unconfined compressive strength of natural clay was improved due addition of 4%, 6% and 8% PTA. At 10% PTA, the clay compressive strength was decreased as shown in CBR and direct shear tests. The results indicate that the maximum compressive strength was found in the clay treated with 8% PTA.

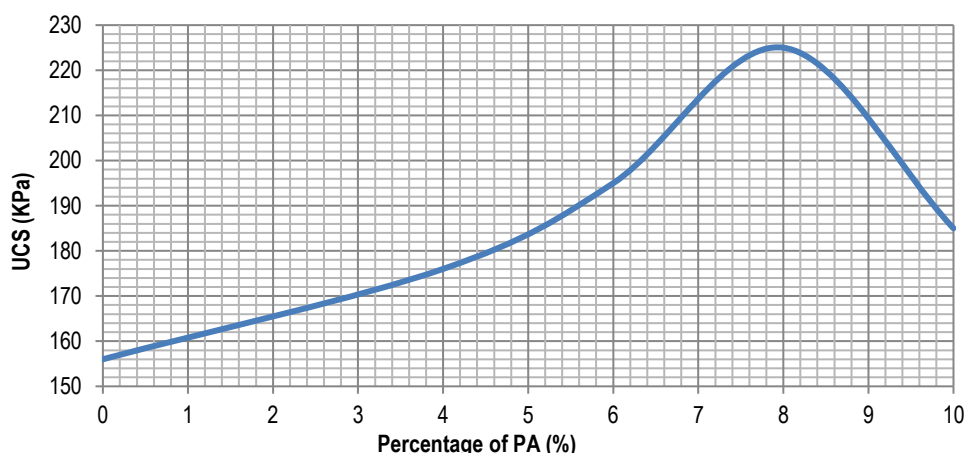


Fig. 5 Unconfined Compressive Strength of Natural and PA stabilized Clay

4. Conclusions

This research was conducted to evaluate some geotechnical characteristics of clay stabilized with Piliostigma Thonningi Pod Ash (PTA), the study was successful and the following conclusions are drawn:

- Maximum dry density was increased as the PTA content increases but optimum moisture content remains constant between 4% to 8% PTA stabilized soil.
- Liquid limit of the natural soil was increased with the increase of PTA content of 4% and 6% but dropped at 8% and 10%, while swelling potential remain almost constant throughout.
- CBR value was increased with the addition of PTA stabilizer to the peak of 100% improvement at 8% PTA.
- The shear strength of the soil was improved by 30% with the addition of 8% PTA.
- The bearing capacity of the soil was also improved by 300% with the addition of 8%. PTA
- In conclusion, 8% is the maximum dosage that can yield a better result, considering 10% PTA always gives lower desirable values.

References

- Oyediran, I. A., & Ayeni, O. O. (2020). Comparative effect of microbial induced calcite precipitate, cement and rice husk ash on the geotechnical properties of soils. *SN Applied Sciences*, 2, 1-12.
- Archibong, G. A., Sunday, E. U., Akudike, J. C., Okeke, O. C., & Amadi, C. (2020). A review of the principles and methods of soil stabilization. *International Journal of Advanced Academic Research Sciences*, 6(3), 2488-9849.
- Usman, N., Masirin, M. I. B. M., Ahmad, K. A., & Wurochekke, A. A. (2018). Residual Moisture as a Source of Distress in Asphaltic Concrete Pavement. *Advanced Science Letters*, 24(6), 3869-3872.
- Keskin, İ., Salimi, M., Ateyşen, E. Ö., Kahraman, S., & Vakili, A. H. (2023). Comparative Study of Swelling Pressure in Expansive Soils considering Different Initial Water Contents and BOFS Stabilization. *Advances in Civil Engineering*, 2023.
- Karami, H., Pooni, J., Robert, D., Costa, S., Li, J., & Setunge, S. (2021). Use of secondary additives in fly ash based soil stabilization for soft subgrades. *Transportation Geotechnics*, 29, 100585.

- [6]. Ma, J., Su, Y., Liu, Y., & Tao, X. (2020). Strength and microfabric of expansive soil improved with rice husk ash and lime. *Advances in Civil Engineering*, 2020, 1-8.
- [7]. Usman, N. (2019). Performance of recycled polymeric fiber as reinforcement in bituminous mixture for road maintenance works (Doctoral dissertation, Universiti Tun Hussein Onn Malaysia).
- [8]. Amakye, S. Y., Abbey, S. J., Booth, C. A., & Mahamadu, A. M. (2021). Enhancing the engineering properties of subgrade materials using processed waste: A review. *Geotechnics*, 1(2), 307-329.
- [9]. Hailemariam, M. B., Woldu, Z., Asfaw, Z., & Lulekal, E. (2021). Ethnobotany of an indigenous tree *Piliostigma thonningii* (Schumacher.) Milne-Redh. (Fabaceae) in the arid and semi-arid areas of South Omo Zone, southern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 17(1), 1-18.
- [10]. Ogbiko, C., Chukwunwejim, C., & Okezie, U. (2021). Phytochemical composition, acute toxicity and lipid profile of the methanol leaf extract of *Piliostigma Thonningii* (Fabaceae). *Journal of Pharmaceutical and Allied Sciences*, 18(1).
- [11]. Ginikachukwu, U., Obinna, O., Chukwunonso Eber, C., & Ebele, O. P. (2021). Pharmacognostic Study of the Leaves of *Piliostigma thonningii* Schum (Cesalpiniaceae). *Journal of Advances in Medical and Pharmaceutical Sciences*, 1-9.
- [12]. Olola, B. O. (2021). Acute Oral-toxicity, Anti-inflammatory and Analgesic Effects of Aqueous and Methanolic Bark Extracts of *Piliostigma Thonningii* (Schum) in Mice (Doctoral dissertation, University of Nairobi).
- [13]. Rawayau, U. H., Abdulfatah, A. Y., & Shuaibu, R. B. (2019). Stabilization of expansive soil using *baubhinia thonningii* (kalgo) fruit ash. *Nigeria Journal of Engineering Science and Technology Research* Vol. 5, No. 1, (35-44)
- [14]. Usin, S., & Omolara, D. O. (2022). Phytochemical analysis and evaluation of ethanol and aqueous extracts of *Piliostigma thonningii* leaf for in vitro antioxidant activities. *Nigerian Journal of Biochemistry and Molecular Biology*, 37(1), 72-81.
- [15]. Elkaseem A. (2020). An investigation in the use of *Piliostigma Thonningii* Pod Ash as an Admixture in Mortar. PGD thesis, Civil Engineering Department, Bayero University Kano, Nigeria.
- [16]. Jiang, N., Wang, C., Wang, Z., Li, B., & Liu, Y. A. (2021). Strength characteristics and microstructure of cement stabilized soft soil admixed with silica fume. *Materials*, 14(8), 1929.
- [17]. Ogila, W. A. M. (2021). Effectiveness of fresh cement kiln dust as a soil stabilizer and stabilization mechanism of high swelling clays. *Environmental Earth Sciences*, 80(7), 283.
- [18]. Adedokun, S. I., Osulale, O. M., Apata, A. C., Elsaigh, W. A., Ikotun, B. D., & Oluremi, J. R. (2022). Geotechnical beneficiation of the strength indices of lateritic soil using steel slag and cement. In *International Journal of Engineering Research in Africa* (Vol. 59, pp. 101-117). Trans Tech Publications Ltd.
- [19]. Michael E.K. (2011). *Soil mechanics laboratory manual*. Hamilton Printing company, 2nd Edition pp. 151
- [20]. Ramdas, V. M., Mandree, P., Mgangira, M., Mukaratirwa, S., Laloo, R., & Ramchuran, S. (2021). Review of current and future bio-based stabilisation products (enzymatic and polymeric) for road construction materials. *Transportation Geotechnics*, 27, 100458.