

Effect of Compaction Delays on the Strength Characteristics of Periwinkle Shell Ash (PSA)-Stabilized Lateritic Soil

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ABSTRACT

The soil's compaction characteristics significantly influence the strength and stability of structures found in the soil. This study examines the impact of compaction delays on the properties of lateritic soil stabilized with Periwinkle Shell Ash (PSA). The lateritic soil was treated with varying PSA contents of 0%, 2%, 4%, 6%, 8%, and 10%. Standard Proctor (BSL) compaction was employed, with compaction delays of 0, 2, 4, and 6 hours. The prepared soil samples were evaluated for their index and engineering properties by BS1377 (1990) and BS1924 (1990) standards. The results classified the soil as A-6 (5) under the AASHTO classification system. The California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of the PSA-stabilized soils exhibited a decreasing trend with increasing compaction delay across all compaction efforts. The findings suggest that compaction delays should not exceed 2 hours to maintain optimal soil performance and highlight the importance of timely compaction in enhancing the engineering properties of stabilized soils.

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INTRODUCTION

Soil is majorly used as primary construction material in many civil engineering structures including embankments, roads, slopes, dams, etc. Weak or problematic soils which have been dispersed in many places worldwide are often encountered in the construction of these civil engineering structures (Mosavat et al, 2012). Problematic soils are characterized with high compressibility, low shear strength, high volume changes, poor drainage and excessive settlement, thus, not fit as construction material in its natural state (Latifi, et al., 2017, Ola, 1978). Soil stabilization is one of the most widely applied techniques of improving the engineering properties of this type of soil to make it fit as construction or foundation material.

The stabilization in the early period is been practiced with cementitious industrial products, such as Portland cement, lime and bitumen (Sherwood, 1993, Andavan & Kumar, 2020, Anburuvel, 2024, Suparma & Rifa'i, 2024). The side effect of production of these materials

couple with greenhouse effect which depletes ozone layer and significantly contributes to global warming and other environmental hazards discourages the utilization of these materials (Lim, et al. 2020, Mohamad, et al. 2022, Mishra et al. 2022). This has led to many researches on possibility of replacing or reducing the use of these materials in soil stabilization.

Agricultural waste such as rice husk ash, coconut shell ash, millet husk ash, periwinkle shell ash, bagasse ash, etc. and industrial waste such as the blast furnace slag, cement kiln dust, calcium carbide, etc. have extensively been investigated for possible cement, lime and bitumen replacement in soil stabilization. For instance, Yoobanpot & Jamsawang, (2014) studied the potential of cement and rice husk ash for soft soil improvement and found that rice husk ash can substantially substitute up to 30% cement content in soil stabilization. Ghadir & Ranjbar (2018) compares the mechanical performance of clayey soil stabilized with volcanic ash-based geopolymer and cement. They concluded that

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geopolymer significantly improve the mechanical performance of the stabilized soil especially at the dry conditions. Moreover, Liu, et al., (2019) utilizes cementing material from rice husk ash (RHS) and calcium carbide residue (CCR) and stabilized expansive soil and their findings indicates that RHA-CCR mixture significantly improve the strength characteristics of expansive soil and make them suitable for airfield foundation, road and railway subgrade, dam filler and other earthworks. More so, Anoop, et al., (2017) investigated the potential of lime and egg shell powder in soil stabilization; and found that egg shell powder replaces up 25% of the lime used in soil stabilization process.

Periwinkle shells are waste generated when edible part of the periwinkle have been removed (Ekop et al. 2013, Offiong & Akpan, 2017). It is an agricultural waste often disposed in open spaces in riverine and coastal areas. Thus, contribute to environmental challenges due to large quantities produced on daily basis. Among the sustainable ways of disposing periwinkle shell is its utilization as construction materials (Ohimain et al. 2009). Hence, it has successfully being utilized in concrete technology and soil stabilization (Ruslan, et al. 2021, Etim et al. 2022, Offiong & Akpan, 2017, Yusuf et al. 2024).

Densification of soil through compaction is a known phenomenon for improving soil strength and stability, and reduces permeability and compressibility of the compacted soil (Kodikara, et al. 2018, Nazari et al, 2021). In road construction, large volume of soil is required which are placed in layers and compacted at predetermined thickness before subsequent layers are added. Delay in compaction is an inevitable situation resulting from technical and logistics challenges during construction and is believed to alter the compaction behavior of stabilized soil (Raja & Thyagaraj, 2020).

Many researchers have investigated the effect of compaction delay on the properties of soil stabilized with various types of stabilizers. For instance, Osuolale, et al. (2017) have studies effect of compaction delay on the strength of lateritic soil stabilized with cement, and established an elapsed time beyond 2 h to be

more prominent in changing the behavior of the stabilized soil. Raja and Thyagaraj (2020) studied the effect of compaction delay on compaction and strength behavior of lime-treated expansive soil contacted with sulfate and found that the effect of compaction delay was negligible on the maximum dry unit weight and the changes were reflected on the strength of lime-treated expansive soil. Osunibi (1998) studied the influence of compactive efforts and compaction delays the properties of lime-treated soil and found that compaction delays gives the minimum compaction and strength properties that can be achieved in the field for the specified elapsed times between mixing and compaction.

From the forgoing researches on compaction delays have stressed on the effect of compaction delay on the strength and stability of stabilized soil and it is proved to be an inevitable phenomena. Although previous researches such as Yusuf et al, (2024), Etim et al (2022), Etim et al (2021), Oke et al (2022) have established the potential of using periwinkle shell ash as soil stabilizer, but the effect of compaction delay on the properties of periwinkle shell ash – stabilized lateritic soil was not clearly studied and thus, it is the focus of this paper. The percentage of PSA used in this study is between 0 to 8% as suggested by Yusuf et al, (2024). Moreover, the delays were extended up to 6 h to clearly study a longer time delay from previous studies. This is to observe whether delays for this type of additive is beyond the 2 hr often suggested by previous studies on other materials.

MATERIALS AND METHODS

Materials

The material used in this study include soil, periwinkle shell ash and water. The soil used in this study was obtained from a burrow pit located at Mahuwa village in Tofa local government area of Kano State, Nigeria. It is located at 11°50' N latitude and 13°09' E longitude. The soil was obtained from 0.5 m depth and was subjected to index and engineering properties tests in accordance with standard procedure outlined in BS1377 (1990). Moreover, the soil was also subjected to X-Ray Diffraction (XRD) and X-

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Ray Florescence (XRF) for further classification. The particle size distribution of the soil and the summary of the properties of the soil are

presented in Figure 1 and Table 1, respectively. Similarly, the results of XRD and XRF tests are presented in Figure 2 and Table 2, respectively.

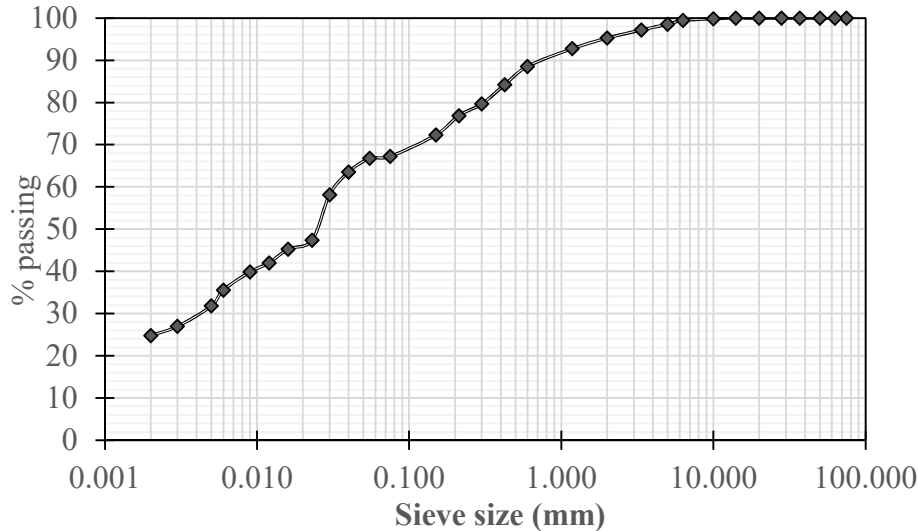


Figure 1. Particle size distribution curve of the soil

Table 2. Properties of the soil

Soil properties	Values
Specific gravity	2.66
Percentage passing No. 200 sieve	67.22
Liquid limit (%)	36
Plastic limit (%)	16
Plasticity index (%)	20
Maximum dry density (Mg/m ³) (BSL)	1.72
Optimum moisture content (%) (BSL)	15.34
Maximum dry density (Mg/m ³) (BSH)	1.86
Optimum moisture content (%) (BSH)	11.78
Maximum dry density (Mg/m ³) (WAS)	1.76
Optimum moisture content (%) (WAS)	13.21
AASHTO classification	A-6
Group Index	5
Unsoaked CBR (%)	26
Soaked CBR (%)	12
UCS (kN/m ²)	44
Major clay mineral	Kaolinite

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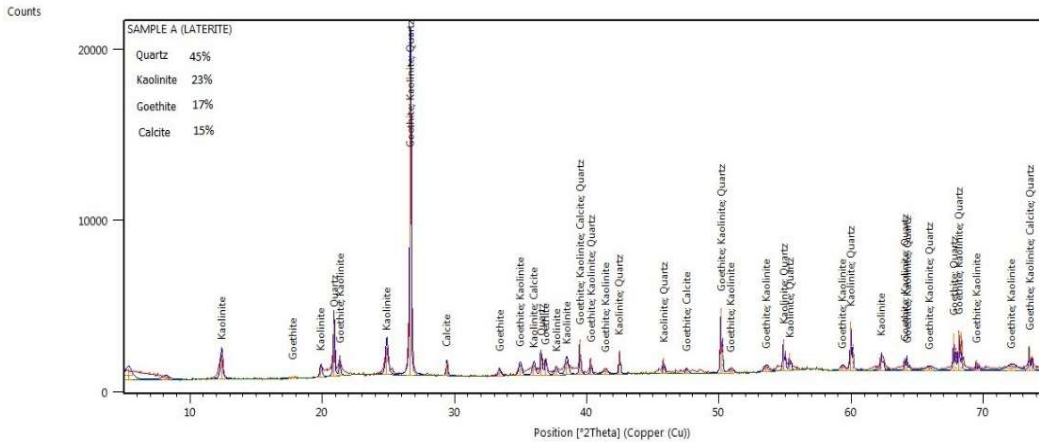


Figure 2: Mineralogical composition of the soil

The XRD results presented in Figure 2. The XRD pattern exhibits distinct peaks corresponding to the crystalline phases in the sample. The most prominent peaks are observed in the 2θ range of 25°-30°, which are characteristic of quartz. Additional peaks corresponding to kaolinite, goethite, and calcite are also evident, indicating a complex

mineralogical composition in the soil with kaolinite been the major clay mineral presence in the soil. From Table 2, the degree of laterization was determined by estimating the silica sesquioxide ratio (Gidigas, 1972) using equation 1. The soil has a silica sesquioxide ratio value of 1.37 which indicates that it is a lateritic soil.

Table 2: Chemical composition of the soil

Oxide composition (%)	Values
CaO	0.25
SiO ₂	48.226
Al ₂ O ₃	20.270
Fe ₂ O ₃	14.856
TiO ₂	3.102
K ₂ O	4.027
MnO	0.04
CuO	0.011
LOI	5.28

$$\text{Silica sesquioxide ratio} = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \quad 1$$

The PSA was produced by burning the periwinkle shell at 650°C for four hours (Etim et

al, 2022) to produce the ash (periwinkle shell ash) and it was subjected to XRF test to further determine its constituent as presented in Table 3.



Table 3: Chemical composition of the PSA

Oxide composition (%)	Values
CaO	38.65
SiO ₂	34.28
Al ₂ O ₃	15.49
Fe ₂ O ₃	6.02
BaO	0.12
Cr ₂ O ₃	0.04
TiO ₂	0.04
K ₂ O	0.03
ZrO ₂	0.03
MnO	0.02
CuO	0.002
SO ₃	0.001
LOI	5.28

The XRF test on the PSA has indicated that the ash predominantly contained calcium oxide (CaO), silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), and iron (III) oxide (Fe₂O₃) as major constituents.

Methods

The test specimens were prepared by thoroughly mixing a predetermined quantities of the dry soil and PSA in a mixing tray to form a homogeneous mixture. This was further mixed with predetermined quantity of portable water obtained from Civil engineering laboratory of Bayero University, Kano, Nigeria.

An air-dried soil sample was thoroughly mixed with 0 to 8% PSA content, and the compaction delays were carried out at different time between maxing the prepared soil with water and compaction for an interval of 0, 2, 4 and 6 hours elapsed time after mixing. The delayed samples were subjected to compaction test, unconfined compressive strength test and California bearing ratio test in accordance with

procedure outlined in BS1377 (1990) and BS1924 (1990). The BSL was chosen because it is easily achieved in the field (Etim, Eberemu et al. 2017). The samples for the CBR and UCS tests were prepared at OMC and MDD of the samples.

RESULTS AND DISCUSSION

Compaction Characteristics

Figure 4 presents the variations of the MDD of PSA-stabilized lateritic soils with the different compaction delays. The findings underscore the critical role of compaction timing in the performance of PSA-stabilized lateritic soil. The initial increase in MDD with PSA addition highlights the potential of using PSA as sustainable materials for soil stabilization. However, the observed decline in MDD with increased compaction delay emphasizes the need for timely compaction to maintain optimal soil density. The results suggest that while PSA enhances soil properties, delays in compaction can negate these benefits, leading to reduced strength characteristics.

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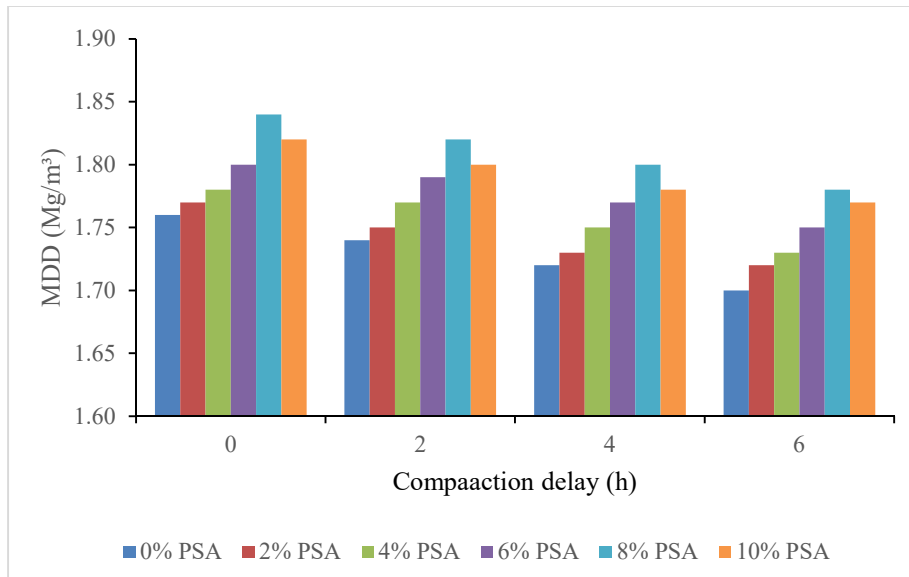


Figure 3. Variations of the MDD of PSA-stabilized lateritic soil with different compaction delays

It can be observed from this Figure that at 0-hour delay, the MDD values range from approximately 1.75 Mg/m³ for unstabilized soil (0% PSA) to 1.83 Mg/m³ for 8% PSA content, indicating an initial positive effect of PSA addition on soil density (Yusuf et al., 2024). As compaction delay increases from 0 to 6 hours, a consistent declining trend in MDD is observed across all PSA contents. This phenomenon aligns with findings by (Nazari et al. 2021 and Nwaiwu et al., 2022), who attributed such behavior to moisture loss and soil particle rearrangement during delay periods. 8% PSA consistently shows the highest MDD values across all delay periods. Lower PSA contents (2-4%) demonstrate moderate improvements over

unstabilized soil and 10% PSA exhibits slightly reduced effectiveness compared to 8%, suggesting an optimal PSA content threshold (Yusuf et al., 2024). The rate of MDD reduction varies with delay time, a rapid decrease is observed in the first 2 hours, moderate reduction between 2-4 hours and gradual reduction was noticed from 4-6 hours. This behavior correlates with findings by Domphoeun, et al. (2025).

The variation of OMC with time delay is presented in Figure 4. For all PSA percentages, the OMC decreases as the compaction delay increases from 0 to 6 hours. Higher PSA percentages generally correspond to lower OMC values at all compaction delays.

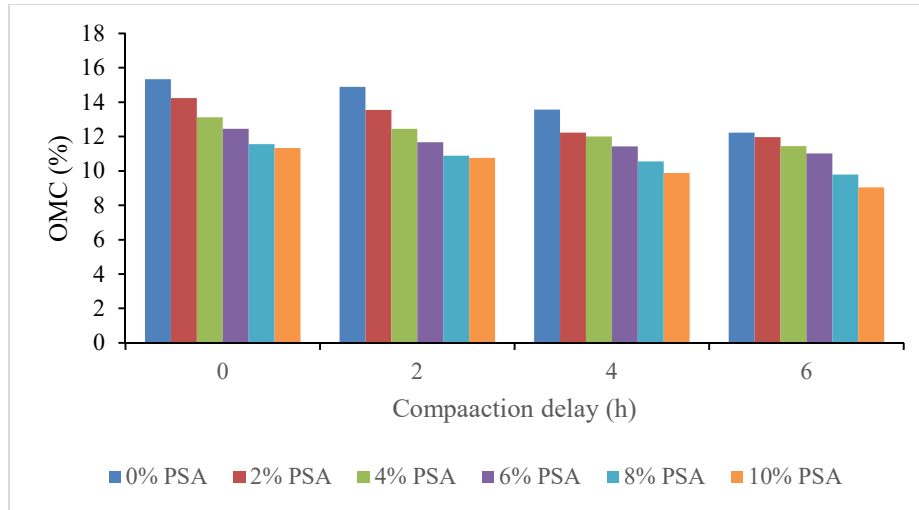


Figure 4. Variations of the OMC of PSA-stabilized lateritic soil with different compaction delays

The decrease in OMC with increasing compaction delay is likely due to the hydration and pozzolanic reactions that occur over time, which reduced the free water available for compaction in the mixed soil. This phenomenon has been reported in studies on delayed compaction of stabilized soils (Kodikara et al., 2018). The results suggest that both PSA content and compaction timing are critical factors in achieving optimal soil compaction. Delayed compaction may lead to

reduced moisture requirements, but excessive delays could compromise the strength and durability of the stabilized material.

Effect of Compaction delay on California Bearing Ratio (CBR) of the lateritic Soil

The relationship between compaction delays and the CBR of the lateritic soil stabilized with varying percentages of PSA is presented in Figure 5.

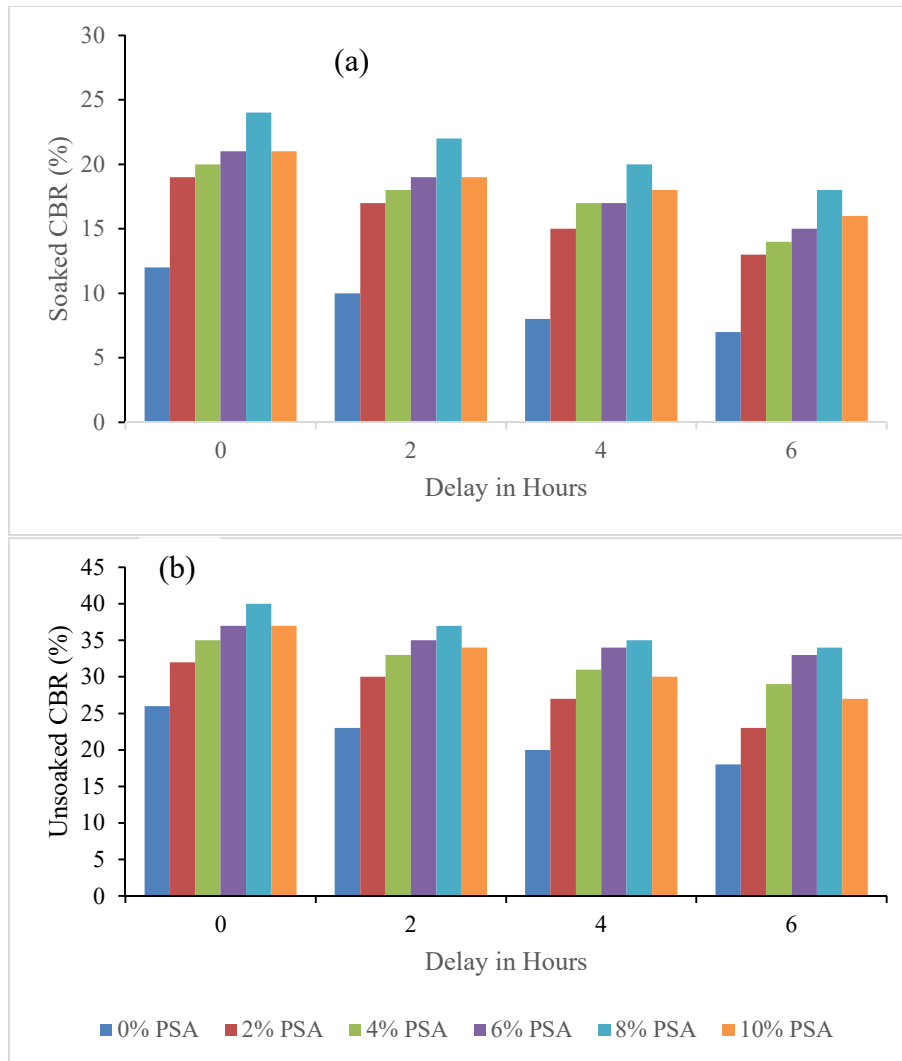


Figure 5. Variations of (a) unsoaked CBR and (b) soaked CBR of PSA-stabilized lateritic soil with different compaction delays

At 0 hours delay, the unsoaked CBR increases with PSA content, peaking at 8% PSA. The unsoaked CBR ranges from approximately 25% at 0% PSA content to 42% at 8% PSA content, and then slightly decreases at 10% PSA. A similar trend is observed for other compaction delays (2, 4, and 6 hours), where 8% PSA consistently yields the highest CBR values. At 6 hours delay, the unsoaked CBR decreases to approximately 18% for 0% PSA content and 35% at 8% PSA content.

For all the PSA percentages, both unsoaked and soaked CBR decreases as the compaction delay increases from 0 to 6 hours. Likewise, the soaked CBR exhibit similar trends. These results highlight the importance of timely compaction in achieving optimal strength characteristics in PSA-stabilized lateritic soil. Delayed compaction leads to a reduction in the CBR values, likely due to moisture loss and reduced bonding between soil particles

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and PSA. These findings are in agreement with that of Osinubi (1998).

The most significant drop in CBR values occurs within the first 2 hours of delay, followed by a more gradual decrease up to 6 hours. This phenomenon is consistent with findings by Joel and Agbede (2011), who demonstrated that early compaction is crucial for achieving maximum strength in stabilized soils.

Effect of Compaction delay on Unconfined Compressive Strength (UCS) of the lateritic Soil

The relationship between compaction delays and the UCS of lateritic soil stabilized with varying percentages of PSA is presented in Figure 6.

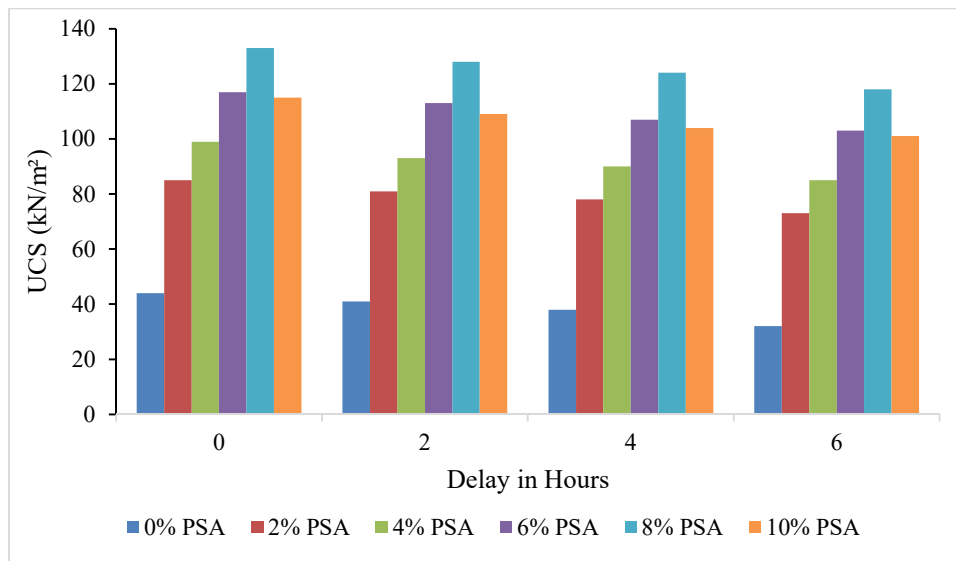


Figure 6. Variations of the UCS of PSA-stabilized lateritic soil with different compaction delays

The UCS values generally decrease as the compaction delay increases for all the PSA contents. This indicates that delayed compaction negatively impacts the strength characteristics of the PSA-stabilized soil. At 0 hours delay, the UCS values are the highest across all PSA percentages, with 8% PSA achieving the maximum UCS of approximately 130 kN/m². The 2 hours compaction delay depicts a slightly decreasing trend compared to 0 hours, while the 6 hours delay, exhibit the lowest values across all PSA percentages, indicating that prolonged delays significantly weaken the soil's strength. The results suggest that immediate compaction after mixing PSA with lateritic soil is crucial for achieving optimal strength. Delayed compaction allows for hydration reactions to occur prematurely,

reducing the bonding and strength development in the soil matrix. Additionally, the optimal PSA content of 8% indicates that excessive PSA (e.g., 10%) may lead to a reduction in strength due to potential over-stabilization or insufficient soil-ash interaction. Thus, the soil-PSA mixture should be compacted within 0 – 2 hours of mixing and to use 8% PSA content for optimal performance. The trend observed is similar to that of Osinubi (1998) and Amu et al., (2011) and Nazari, et al. (2021).

CONCLUSION

This study provides valuable insights into the effects of compaction delays on the strength characteristics of lateritic soil stabilized with pulverized steel ash (PSA). The findings emphasize the critical role of timely compaction in

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ensuring the effectiveness of soil stabilization techniques. Delayed compaction can significantly impact the mechanical properties of the stabilized soil, potentially reducing its strength and long-term durability.

Through a series of controlled laboratory experiments, the study demonstrates that the strength of PSA-stabilized lateritic soil is highly dependent on both the time elapsed before compaction and the percentage of PSA used. The results highlight that immediate or early compaction, ideally within 0–2 hours of mixing, leads to enhanced soil strength by allowing optimal hydration and bonding of particles. Conversely, prolonged delays before compaction result in decreased strength due to moisture loss and reduced reactivity of PSA with the soil matrix.

Furthermore, the study identifies 8% PSA as the optimal content for stabilization, as it provides the best balance between workability, strength, and durability. This finding is crucial for civil engineers and construction professionals seeking to improve the performance of lateritic soil in road construction, foundation work, and other geotechnical applications.

In practical terms, the study highlights the necessity of adopting best practices in soil stabilization by ensuring minimal delays in compaction and maintaining an appropriate PSA dosage. By following these recommendations, construction projects can achieve higher soil strength, increased load-bearing capacity, and improved longevity of stabilized structures.

REFERENCES

- Ali, H., & Mohamed, M. (2017). The effects of compaction delay and environmental temperature on the mechanical and hydraulic properties of lime-stabilized extremely high plastic clays. *Applied Clay Science*, 150, 333-341.
- Amu, O. O., Ogunniyi, S. A., & Oladeji, O. O. (2011). "Geotechnical Properties of Lateritic Soil Stabilized with Periwinkle Shell Ash." *Journal of Applied Sciences and Environmental Management*, 15(2), 241-246.
- Anburuvel, A. (2024). The engineering behind soil stabilization with additives: a state-of-the-art review. *Geotechnical and Geological Engineering*, 42(1), 1-42.
- Andavan, S., & Kumar, B. M. (2020). Case study on soil stabilization by using bitumen emulsions—A review. *Materials Today: Proceedings*, 22, 1200-1202.
- Anoop, S. P., Beegom, H., Johnson, J. P., Midhula, J., TN, T. M., & Prasanth, S. (2017). Potential of egg shell powder as replacement of lime in soil stabilization. *International Journal of Advanced Engineering Research and Science*, 4(8), 237244.
- Bello, A. A. (2011). Influence of compaction delay on CBR and UCS of cement stabilized lateritic soil. *The Pacific Journal of Science and Technology*, 12(2), 87-96.
- Di Sante, M., Fratalocchi, E., Mazzieri, F., & Brianzoni, V. (2015). Influence of delayed compaction on the compressibility and hydraulic conductivity of soil–lime mixtures. *Engineering Geology*, 185, 131-138.
- Dompheun, R., Eisazadeh, A., & Nishimura, S. (2025). Strength Properties of Laterite Soil Stabilized with Rice Husk Ash and Lime as Road Material. *Transportation Infrastructure Geotechnolgy*, 12(1), 1-17.
- Ekop, E., Adenuga, O. A. and Umoh, A. A. (2013). Strength characteristics of granite – *pachimalania aurita* shell concrete, *Nigerian journal of Agriculture, Food and Environment*, vol. 9, issue 2, pp. 9-14.
- Etim, R. K., Ekpo, D. U., Udofia, G. E., & Attah, I. C. (2022). Evaluation of lateritic soil stabilized with lime and periwinkle shell ash (PSA) admixture bound for sustainable road materials. *Innovative Infrastructure Solutions*, 7, 1-17.
- Ghadir, P., & Ranjbar, N. (2018). Clayey soil stabilization using geopolymer and Portland cement. *Construction and Building Materials*, 188, 361-371.

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- Kodikara, J., Islam, T., & Sounthararajah, A. (2018). Review of soil compaction: History and recent developments. *Transportation Geotechnics*, 17, 24-34.
- Latifi, N., Horpibulsuk, S., Meehan, C. L., Abd Majid, M. Z., Tahir, M. M., & Mohamad, E. T. (2017). Improvement of problematic soils with biopolymer—an environmentally friendly soil stabilizer. *Journal of Materials in Civil Engineering*, 29(2), 04016204.
- Lim, C., Jung, E., Lee, S., Jang, C., Oh, C., & Shin, K. N. (2020). Global trend of cement production and utilization of circular resources. *Journal of Energy Engineering*, 29(3), 57-63.
- Liu, Y., Chang, C. W., Namdar, A., She, Y., Lin, C. H., Yuan, X., & Yang, Q. (2019). Stabilization of expansive soil using cementing material from rice husk ash and calcium carbide residue. *Construction and Building Materials*, 221, 1-11.
- Mishra, U. C., Sarsaiya, S., & Gupta, A. (2022). A systematic review on the impact of cement industries on the natural environment. *Environmental Science and Pollution Research*, 29(13), 18440-18451.
- Moghal, A. A. B., Ashfaq, M., Al-Obaid, A. A. K. H., Abbas, M. F., Al-Mahbashi, A. M., & Shaker, A. A. (2021). Compaction delay and its effect on the geotechnical properties of lime treated semi-arid soils. *Road Materials and Pavement Design*, 22(11), 2626-2640.
- Mohamad, N., Muthusamy, K., Embong, R., Kusbiantoro, A., & Hashim, M. H. (2022). Environmental impact of cement production and Solutions: A review. *Materials Today: Proceedings*, 48, 741-746.
- Mosavat, N., Oh, E., & Chai, G. (2012). A review of electrokinetic treatment technique for improving the engineering characteristics of low permeable problematic soils. *GEOMATE Journal*, 2(4), 266-272.
- Nawaz, M. F., Bourrie, G., & Trolard, F. (2013). Soil compaction impact and modelling. A review. *Agronomy for sustainable development*, 33, 291-309.
- Nazari, Z., Tabarsa, A., & Latifi, N. (2021). Effect of compaction delay on the strength and consolidation properties of cement-stabilized subgrade soil. *Transportation Geotechnics*, 27, 100495.
- Nwaiwu, C. M., Ubani, O. U., & Mahawayi, C. (2022). Influence of Compaction Delay on the CBR and Compaction Behaviour of Cement Treated Lateritic Gravels. *Jordan Journal of Civil Engineering*, 16(1).
- Offiong, U. D. and Akpan, G. E. (2017). Assessment of Physico-Chemical Properties of Periwinkle Shell Ash as Partial Replacement for Cement in Concrete. *International Journal of Scientific Engineering and Science*, Volume 1, Issue 7, pp. 33-36, 2017.
- Ohimain, E. I., Basse, S. and Bawo, D. S. (2009) "Uses of seas shells for civil construction works in coastal Bayelsa State, Nigeria: A waste management perspective," *Research Journal of Biological Sciences*, vol. 4, issue 9, pp. 1025-1031.
- Oke, J. A., Obaji, N. O. and Ikoya, A. A. (2022). Strength characteristics of oyster shell ash and periwinkle shell ash stabilized lateritic soil for pavement construction. *Journal of Science and Technology research* 4(4) pp 72-89
- Ola, S. A. (1978). Geotechnical properties and behaviour of some stabilized Nigerian lateritic soils. *Quarterly Journal of Engineering Geology and Hydrogeology*, 11(2), 145-160.
- Ola, S. A. (1978). The geology and geotechnical properties of the black cotton soils of northeastern Nigeria. *Engineering Geology*, 12, 375-391.
- Osinubi, K. J. (1998). "Influence of Compaction Delay on the Properties of Cement-



- Stabilized Lateritic Soil." *Journal of Engineering Research*, 6(1), 13-25.
- Osinubi, K. J. (1998). Influence of compactive efforts and compaction delays on lime-treated soil. *Journal of transportation engineering*, 124(2), 149-155.
- Osinubi, K. J., & Nwaiwu, C. M. (2006). Compaction delay effects on properties of lime-treated soil. *Journal of materials in Civil Engineering*, 18(2), 250-258.
- Osuolale, O. M., Olawuyi, O. A., Busari, A. and Adewumi, A. S. (2017). Effect of compaction delay on the strength of cement stabilised lateritic soil. *LAUTECH Journal of Engineering and Technology* 11(1) 2017: 47-51
- Raja, P. S. K., & Thyagaraj, T. (2020). Effect of compaction time delay on compaction and strength behavior of lime-treated expansive soil contacted with sulfate. *Innovative Infrastructure Solutions*, 5(1), 14.
- Raja, P. S. K., & Thyagaraj, T. (2021). Significance of compaction time delay on compaction and strength characteristics of sulfate resistant cement-treated expansive soil. *Journal of Rock Mechanics and Geotechnical Engineering*, 13(5), 1193-1202.
- Ruslan, H. N., Muthusamy, K., Mohsin, S. M. S., & Kirgiz, M. S. (2021). Periwinkle Shell as Mixing Ingredient in Concrete: A Review. *Construction*, 1(2), 21-30.
- Sherwood, P. (1993). *Soil stabilization with cement and lime*. TRL, Crowthorne, Berks, pp. 153, ISBN, 9780115511714, 0115511717
- Sivapullaiah, P. V., Prashanth, J. P., & Sridharan, A. (1998). Delay in compaction and importance of the lime fixation point on the strength and compaction characteristics of soil. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, 2(1), 27-32.
- Suparna, L. B., & Rifa'i, A. (2024). Determination of Optimum Cement Content for Silty Sand Soil Stabilization as the Base Course. *Geomate Journal*, 26(115), 124-133.
- Yoobanpot, N., & Jamsawang, P. (2014). Effect of cement replacement by rice husk ash on soft soil stabilization. *Agriculture and Natural Resources*, 48(2), 323-332.
- Yusuf, S., Yunusa, G. H., Suleiman, A., & Talib, Z. A. (2024). The Effect of Periwinkle Shell Ash (PSA) On Geotechnical Properties of Lateritic Soil for Road Construction Application. *Platform: A Journal of Engineering*, 8(3), 52-61.

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