Enhancing the Geotechnical Properties of Lateritic Soil Using Binary Composite of Periwinkle Shell Ash and Steel Slag for Highway Construction

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Abstract - **This study investigates the potential of Periwinkle Shell Ash (PSA) and Steel Slag (SS) as eco-friendly stabilizers for lateritic soils used in highway construction. Laboratory tests, including Atterberg limits, Proctor compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS), were performed on natural soil and soil-stabilizer blends. Results indicate that PSA and SS significantly enhance soil strength, with optimal performance observed at 15–20% replacement levels. This binary composite reduces plasticity, increases load-bearing capacity, and offers a sustainable alternative to conventional stabilizers in Nigeria's road construction sector.**

Keywords: Geotechnical, Lateritic Soil, Periwinkle Shell Ash, PSA, Steel Slag, SS, Highway Construction.

I. INTRODUCTION

Lateritic soils are widely used as subgrade and base materials in highway construction, particularly in tropical regions. However, their geotechnical properties often fall short of the required engineering standards, leading to early pavement failures. The search for sustainable and cost-effective soil stabilizers has led to the consideration of industrial and agricultural waste materials. Periwinkle Shell Ash (PSA), a by-product of shellfish consumption, and Steel Slag (SS), a residue from steel production, offer potential as eco-friendly stabilizers due to their pozzolanic and cementitious properties. This study explores the synergistic effect of PSA and SS on the geotechnical performance of lateritic soil for highway infrastructure. The increase in urbanization has led to the development of more facilities like roads, railways, underground tunnels etc. In a developed country, there is a need to provide adequate transportation facilities for the enormously increasing population and also the maintenance of the existing ones is equally important. As a result of excess loads placed on roads which are the most useful means of transportation in Nigeria, the roads have over time gradually retrogressed to a dilapidated condition and have now remained a major problem for the nation thereby causing economic downtrodden in the country (Oke *et al.,* 2022).

Alarming rate of highway pavement failure is a major concern in Nigeria and it has been attributed to substandard foundation materials and other factors (osuolale, 2012). Therefore, highway engineers are faced with the problems of providing very suitable and stable materials for highway construction which makes construction industries to overly depend on the conventional soil stabilizing agents. (Amu *et al.,* 2011). In achieving this, individuals, firms and institutions are continuously researching ways to improve the engineering properties of highway pavement materials, specifically lateritic soil. Most of available lateritic soils do not have adequate engineering properties to really bear the expected wheel load, therefore an improvement has to be made to make these soils better with sufficient strength. This leads to the concept called soil stabilization which is the treatment applied to a soil to improve its strength and reduce its vulnerability to water. The treated soil is regarded as stable if it could withstand the stresses imposed on it by traffic under all weather conditions without excessive deformation (Amu *et al.,* 2011). In order to measure up with the huge propensity for durable roads, alternative construction materials that are cheaper are to be considered, thereby, keeping the cost of constructing roads considerably low; this also depends on the amount of durable alternatives that can easily be assessed conveniently (Oke and Osinubi 2019). For the purpose of this, it is essential to research more looking for locally sourced material that is cheap and readily available that can serve as alternative construction stabilization additives without compromising key factors such as stability and environmental friendliness of these additives. The ability to blend the naturally abundant lateritic soil with some stabilizing agents to give it better engineering properties in both strength and water proofing has been of most importance to the transportation engineers. The engineering properties of the soil can be improved by chemical stabilization. Stabilizer such as cement, lime and bitumen are commonly used but recent researches have reported potential utilization of agricultural and industrial

wastes such as rice husk, sawdust, corncob, fly ash, steel slag, glass and so on. Chemical stabilization is achieved by mixing thoroughly the stabilizers with soil at required moisture content and then compacting the soil- stabilization mixture to the required density (Vincy and Muttharam, 2009).

Molluscs are organisms which inhabit the moist areas. The Common families are oyster, mussel, cockle and periwinkle. Their shells are mainly composed of $CaCO_3$ which are similar to limestone. Periwinkle is found along the coast of West Africa: from Senegal to Cameroun (Ajang *et al.,* 2015; Appleton *et al.,* 2015). In Nigeria, they inhabit the brackish waters of the Niger Delta area and Lagos lagoon (Abdullahi and Sara, 2015). The periwinkle specie (Tympanotonus fuscatus) inhabits the Niger Delta area of Nigeria (Bob-Manuel, 2012 and Iboh *et al.,* 2015) while another specie, Pachymelania aurita, is found in Badagry, Nigeria. Periwinkle shell is disposed into environment when eating its meat as food. According to Otoko and Cynthia (2014) the quantity of periwinkle shell generated in Port Harcourt, Nigeria is about 6 tons per day. The similarity in the composition of mollusc shells to limestone reveals the essence for both similar reaction and use (Yao *et al.,* 2014). Effective use of periwinkle shell which was hitherto a solid waste, especially in the coastal areas, can best be achieved after its characteristics are known.

Moreover, Steel slag is a by-product of steel manufacturing that is producing during the separation of molten steel from impurities in steel-making furnaces. The slag evolves as a molten liquid and is composed of a complex solution of silicates and oxides that solidifies upon cooling. Steel slag is a recycled material that can be useful in the construction industry. For instance, in year 2002, 50 million metric tons of steel slag was calculated to be generated worldwide (Akin and Yilmas 2001) and 12 million tons was estimated to be produced in Europe. The large amount of generated slags with the environmental impact have motivated engineers and scientists to work on the solutions, based on industrial more friendly concepts that allow using these residues as raw material for pavements (Radenovic *et al.,* 2013). Steel slags may be used in construction of road in replacement of natural aggregates, which reduces the environmental impact by reducing the consumption of natural and non-renewable aggregates and the quantity of slag deposited on landfill sites, both in asphalt (Mladenovic *et al.,* 2015) and cement based roads. Steel slag is generally classified based on its raw materials and production process into basic oxygen furnace (BOF) slag and electric arc furnace (EAF) slag. Unlike blast furnace slag, BOF and EAF slags contain high unhydrated lime (CaO) that causes it to volumetrically expand (Wang *et al.,* 2010) and this limits its use as a construction material. Akinwunmi 2014 also reported steel slag can be used for manufacturing blended cement, used

as aggregate in Portland cement concrete and asphalt concrete and as unbound granular materials for road bases and sub-bases.

According to Bello *et al.,* (2015), laterite is a highly weathered material rich in secondary oxides of Iron, Aluminium or both. It is void or nearly voids of bases, primary silicates, but may contain urge amounts of quartz and kaolinite. They are formed in hot, wet tropical regions with an average annual rainfall of at least 1200 mm and a daily temperature in excess of 25°Cand typically occur in humid tropical climate within 30º N and 30º S of the equator. Laterites develop beneath the surface in soil zones, unconsolidated sediments or decomposed rocks where interrelations of ground water, soil/water table and topography are favourable. A major factor in its formation is an alternating or variable moisture cycle and it is formed in association with grasslands and forests on lowland surfaces in tropical and temperate regions. It has been found that lateritic soils are generally good construction materials and are therefore extensively used in construction. Also, laterites have been defined as a residual of rock decay that is red, reddish in colour and have a high content of oxides of Iron and hydroxides of Aluminium and low proportion of silica. In the tropical part of the world, lateritic soils are used as road making material and they form the subgrade of most tropical roads, also, they are used as subbase and bases for low cost roads and these carry low to medium traffic. In rural areas of Nigeria, they are used as building material for moulding blocks and plastering (Amu and Adetuberu, 2010a). There are five factors that influence the formation of laterites as identified by Ola (1983), they are: climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron rich rocks) and time, of these primary factors, climate is considered to be the most important factor. Most lateritic soils in their natural states generally have low bearing capacity and low strength due to high content of clay. When lateritic soil contains large amount of clay materials its strength and stability cannot be guaranteed under load especially in the presence of moisture, hence, the need for stabilization (Bello *et al.,* 2015).

Highway failures in Nigeria are often attributed to poor subgrade conditions. Conventional stabilizers like cement and lime are expensive and environmentally unfriendly. There is a pressing need to adopt sustainable alternatives that are both economically viable and readily available. This article considered objectives among others are to evaluate the individual and combined effects of PSA and SS on the geotechnical properties of lateritic soil. Likewise, to determine the optimum blend ratio of PSA and SS for maximum soil stabilization. And to assess the suitability of the stabilized soil for use in highway subgrade and base layers.

II. METHODS

The lateritic soil and saw dust was sourced from Aroje in Ogbomoso metropoliss (Latitude 8º16'48" N and Longitude 4º114'02" E) and (Latitude 8º09'00" N and Longitude 4º14'18" E). The periwinkle was obtained from riverine area like Warri in Delta state (Latitude 5º32'43" N and Longitude 5º45'45" E). The steel slag was source from Ikorudu in Lagos state (Latitude 6º40'40" N and Longitude 3º30'56" E).

All the materials was characterized using XRF for stabilizers and the lateritic soil. Also the following laboratory tests was carried out on the natural soil, natural soil and the stabilizers with varying percentage: Natural moisture content, specific gravity, particle sizes analysis, atterberg limit test, compaction, california bearing ratio and unconfined compressive strength. All the geotechnical characteristics on the sample was carried out at geotechnical laboratory civil engineering department Ladoke Akintola University of Technology (LAUTECH) Ogbomoso and Federal Polytechnic Ile-Oluji, Ondo State Nigeria and other places according to BS 1377 and 1924 (1990).

III. RESULTS

Materials Collection: Lateritic soil from a local borrow pit, PSA from Warri, calcinated, and SS from a steel mill in Lagos.

Preliminary Testing: Physical and chemical characterization of all materials. Table 3.1a and b shows the oxide composition of the PSA and SS which reveals that PSA has oxide of Silicon (SiO_2), aluminium (Al2O3) and Iron (Fe_2O_3) with the addition of 43.84% of calcium. Also SS contains oxide of Silicon (SiO_2), aluminium (Al_2O_3) and Iron (FeO) with the addition of 30.20% of calcium.

Table 3.1a: Chemical composition of Periwinkle Shell Ash PSA

Composition	Value %
Fe_2O_3	6.50
SiO_2	32.88
Al_2O_3	11.2
CaO	43.84
MgO	0.58

Table 3.1b: Chemical composition of Steel Slag SS

Composition	Value %
FeO	28.4
SiO_2	20.20
Al_2O_3	5.10
CaO	30.20
MgO	11.40
MnO	0.80
$P2O_3$	0.60

**Soil Stabilization:** Blending soil with varying percentages of PSA (5–20%) and SS (5–20%).

Laboratory Testing: Atterberg limits, Proctor compaction, CBR, and UCS tests will be conducted at each blend ratio. From the geotechnical test in the laboratory, it was discovered that that the soil is weaked for sub-based materials. The results shows that increased in PSA and SS reduced the atterberg limit up to 10% of PSA and SS content which has similarity with FMW 2016. The optimum compaction properties were observed at 15% of PSA and SS content which aligning with result gotten from Nacini *et al.,* 2021. With this concentration the CBR value was significantly improved, although it has lower value which is below 180% required for base construction materials and Cement –stabilized materials. This result also in line with what Mustapha *et al.,* 2005 got in his research. UCS also improved at 10% of PSA and SS but not meet up with 1710KN/m^2 condition for required for Soil modification with Ordinary Portland Cement. However the UCS value was with the range of sub-base used. According to Osinubi *et al.,* 2015.

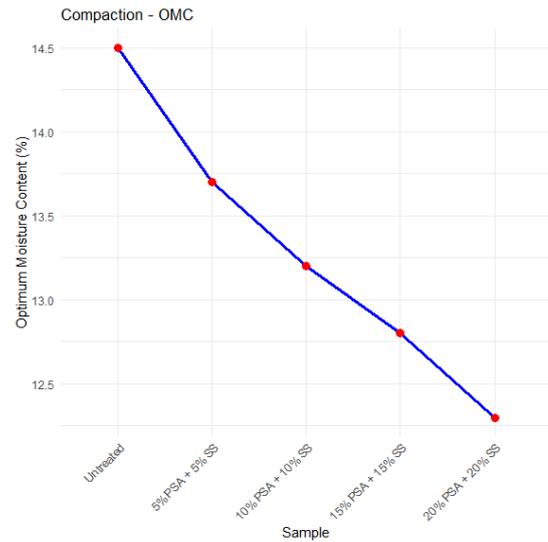**Data Analysis:** Comparative performance analysis and optimization using response surface methodology (RSM).
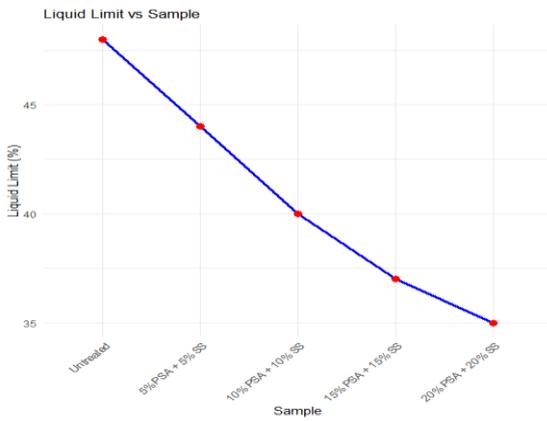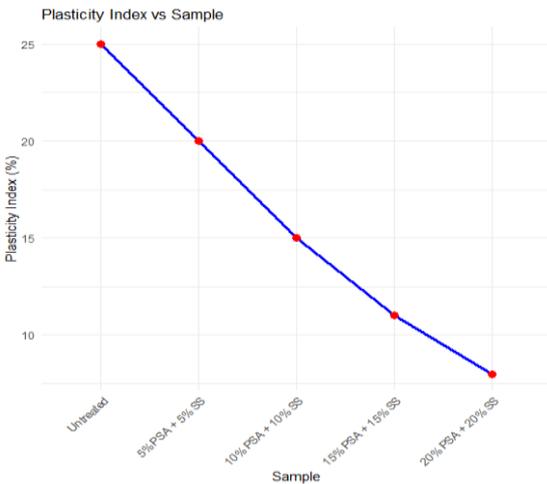
1. Natural Moisture Content

2. Specific Gravity
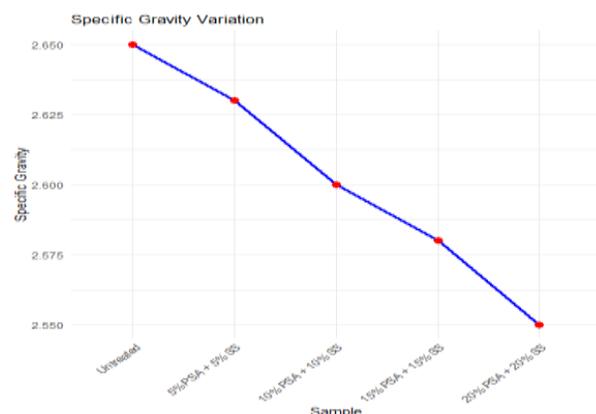
3. Particle Size Analysis (Grain Size Distribution)

Liquid Limit vs Sample

Compaction - OMC

4. Atterberg Limits

Plasticity Index vs Sample

6. California Bearing Ratio (CBR)

California Bearing Ratio (Soaked)
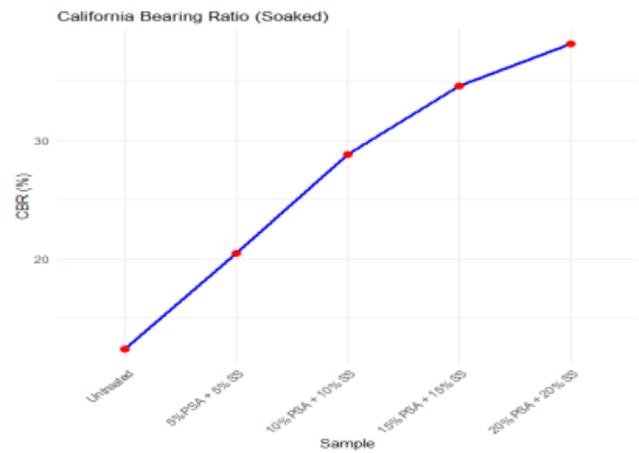
5. Compaction Test (Modified Proctor)

Compaction - MDD

7. Unconfined Compressive Strength (UCS)
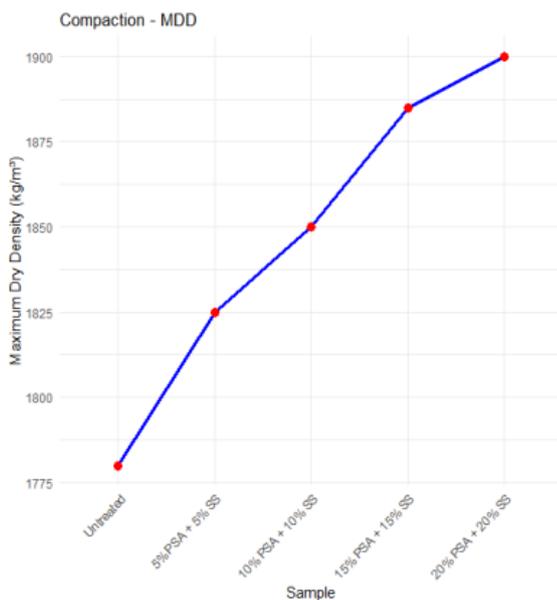

Unconfined Compressive Strength
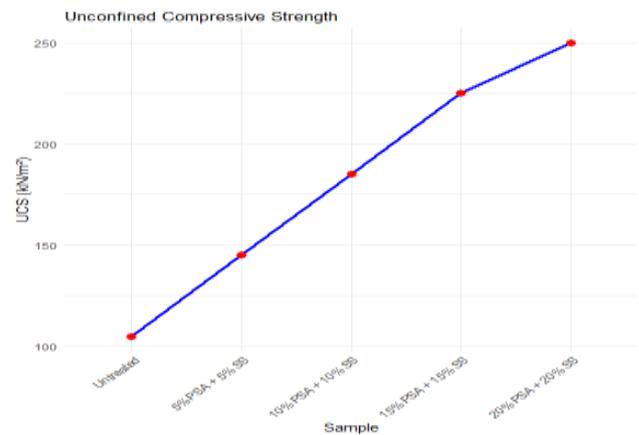
IV. RESULT DISCUSSION

Optimum Improvement was observed around 15–20% PSA and SS, with significant increases in UCS and CBR values, making the soil suitable for subgrade and base course applications. Plasticity Index reduced, indicating improved

workability and reduced shrink-swell potential. Specific Gravity slightly decreased due to the lighter weight of the additives, which is expected. Compaction Characteristics improved, enhancing load-bearing capacity.

Intercept (12): Base CBR value when PSA and SS are at coded level 0 (i.e., 10% real-world value). x_1 (PSA) and x_2 (SS): Positive coefficients show that increasing PSA and SS individually increases CBR. x_1^2 and x_2^2: Negative coefficients indicate diminishing returns at higher values — meaning CBR increases up to a point, then starts to decline. $x_1{:}x_2$ (interaction): Positive interaction suggests synergy — using both PSA and SS together gives better results than using either alone.

Result of Contour Plots

CBR Response Surface   UCS Response Surface
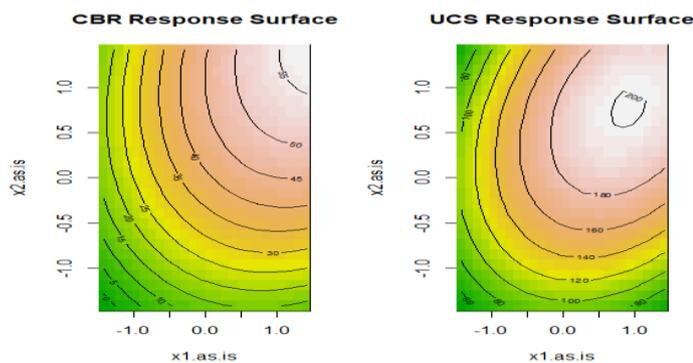
The contour map shows how the CBR changes across combinations of PSA and SS.

Look for the "bullseye" area (high value) in the plot — that's your optimal zone.

For CBR and UCS, highest values should occur near 15–20% PSA and SS, based on the model.

Result of 3D Surface Plots

The 3D surface shows the response curvature.

CBR Surface Plot   UCS Surface Plot
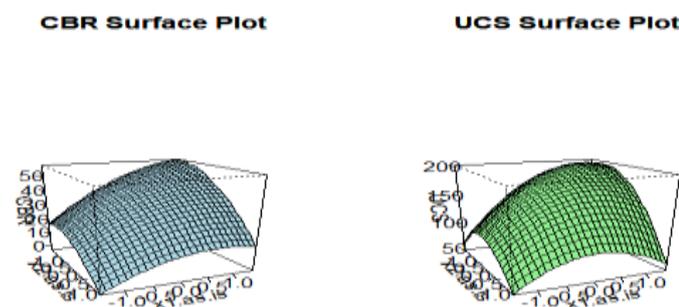
A rising hill or dome shape indicates the response increases to a peak before falling. This confirms that there's an

optimal mix and using too much of either material may reduce performance. Optimum is around: PSA ≈ 15–17%, SS ≈ 15–18%. This region gives maximum CBR/UCS, balancing strength with material efficiency.

V. CONCLUSION

Utilizing a binary composite of PSA and SS for lateritic soil stabilization presents a viable solution to Nigeria's road infrastructure challenges. The outcome of this study could influence highway construction practices and policy decisions towards adopting sustainable materials. Both PSA and SS significantly improve soil strength. Interaction effect is positive, suggesting binary use is better than individual. There's a sweet spot (optimum blend) beyond which performance may decline due to excessive additive content.

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