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GEOTECHNICAL AND MINERALOGICAL CHARACTERISTICS OF LATERITIC SOIL AND LOCUST BEAN (PARKIA BIGLOBOSA) POD ASH AS CONSTRUCTION SOIL

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Abstract — African locust bean (Parkia Biglobosa) has been in great demand and consequently yielding large amounts of the pods which could be a potential hazard to the environment. Converting the pods to ash that would be utilized as construction material is another way of handling them properly. The effects of the mineralogy of the soil on its geotechnical characteristics when the soil is treated with locust bean pod ash have been given very little attention. Therefore, this study considered the effects of locust bean pod ash (LBPA) and the mineralogy of lateritic soil on some geotechnical properties necessary for it to be used as subgrade or foundation soil. The determination of the chemical constituents of the LBPA was carried out using Atomic Absorption Spectrometer. The lateritic soil was characterized by identifying the clay minerals as well as non-clay minerals present in the soil using the x-ray diffraction technique and preliminary tests were also carried out to properly rate the soil. The soil was treated by applying dosages of LBPA 0 – 25% at intervals of 5% and the percentages were measured by weight of the dry soil. The tests conducted on the prepared soil samples with LBPA were specific gravity, consistency indices, compaction (British Standard Light), California bearing ratio and direct shear box test. The LBPA was found to be an acceptable pozzolanic material for the treatment of the lateritic soil. The lateritic soil was observed to belong to soil groups A-2-6(0) in the AASHTO and poorly graded sand (SP) in USCS ratings. It was also observed that the non-clay minerals present in the soil were quartz, feldspar and mica whereas the clay minerals present were kaolinite, iolite, vermiculite and chlorite which had a significant influence on the geotechnical characteristics of the soil. The specific gravity of the LBPA was relatively low and the additions of LBPA reduced the specific gravity of the soil. The consistency indices also dropped and subsequently increased with the further addition of LBPA. The increase in LBPA contents caused increments in the optimum moisture content while the maximum dry density and shear strength parameters reduced. The strength characteristics like the California Bearing Ratio of the lateritic soil improved by 173.91% at the addition of 5% LBSA content which was determined to be the optimum dosage.

Keywords: geotechnical, mineralogical characteristic, locust bean (Parkia Biglobosa) pod ash, subgrade, foundation soil

1.0 INTRODUCTION

African locust bean with the scientific name *Parkia Biglobosa* is a species of plant that belongs to the family of legumes. The pods are usually generated as waste residues after the removal of locust bean seeds during harvest season. The photographs of locust bean pods and locust bean tree are shown in Figures 1 and 2 respectively. African locust beans in a fermented state have been commonly used as food condiments in Africa. Some physical sensory studies indicated that as the fermentation process extends, the odor becomes increasingly pleasant [1]. By the fourth day of the fermentation process, it tends to develop a slimy texture. A proximate analysis carried out by [2] revealed that protein, crude fats and moisture contents increase with a corresponding decrease in carbohydrate content in the process of fermentation. The pulp of the African locust bean fruit is recognized as a valuable protein source, with a crude fiber content of up to 6.56% and 11.75%, respectively, among other essential nutritional components. [3]. *Parkia* flour has been utilized as a supplement/partial replacement for wheat flour in bread making for starch resistance [4]. It has been observed that the inclusion of *Parkia* flour of up to 40% in bread made of wheat flour increases the crude protein content from 7.89 – 15.68%. The escalating demand for locust beans has led to a significant increase in the yield of pods as residues post-seed removal. However, the economic potential of these pod residues remains largely untapped, posing a potential environmental hazard.

Figure 1 Locust bean pods

Figure 2 Locust bean tree

Another name for lateritic soils is residual soils because they are formed by the weathering and leaching of sedentary rocks. The leaching process involves the gradual removal of lighter minerals like silica which culminates into the enrichment of the sesquioxides such as Ferric oxides and Alumina. Lateritic soils are usually prevalent in the tropical region especially in the African sub-region and other parts of the world with high temperature and rainfall which favours the laterization process. Lateritic soil has been of immense benefits to the construction industry because they are almost non-swelling except in rare cases where they possess very troublesome clay minerals. It is usually cost effective to utilize lateritic soils, both in natural or treated form, in civil engineering works in the region because they are abundantly available in local areas. In most cases, they are encountered during construction projects or sometimes transported to the site from short haulage distances. Several previous research attempts have successfully shown lateritic soils to be useful in civil engineering works such as pavement structures, foundation soils, waste containment and other earth embankments [5–13].

Sometimes when soils are deficient in any of the geotechnical characteristics for any civil engineering purpose, the soils are slightly stabilized or modified with cement or lime to boost the properties for any engineering purposes. Consider the enormous cost of cement or lime that would be required for a long stretch of road construction work that involved a modified soil as subgrade. It is imperative to minimize as much as possible the overall cost of the construction work by seeking for an alternative. Serious past efforts had been geared towards utilizing residues from agricultural plants such as rice husk ash [14–16], palm husk ash [17], palm kernel shells ash [18], palm bunch ash [19], and Bagasse ash [20–24] to improve soil geotechnical properties. These agricultural residues should have constituted a nuisance to the environment which would require appropriate handling. The idea of using these agricultural residues for soil improvement is a clear case of converting waste to wealth. Previous studies on the application of locust bean pod to improve soil properties are limited. Daha *et al.* [25] stabilized lateritic soil using powdered locust bean pod while Ige and Oyeniyan [26] as well as Adama *et al.* [27] used locust bean pod ash to treat soil for subgrade purposes. Locust bean pod ash has been found to improve the geotechnical properties of the soils. In these research, the soils that were studied were somewhat fine-grained. Therefore, it is imperative to consider the effect of locust bean pod ash on a coarser soil. Furthermore, soils exhibit unique structural characteristics, making it challenging for any two soils to share common traits across all geotechnical considerations. To illustrate further, while two soils may demonstrate similarities in their consistency indices, they could diverge significantly in terms of particle size gradation, resulting in distinct geotechnical behaviours. From the stand-point of pedogenesis, Gidigasu [28] explored these variabilities comprehensively. Most importantly, the previous studies have limited attempt to consider the effects of soil mineralogy with locust bean pod ash on the geotechnical characteristics of the soils. Therefore, this study focused on the geotechnical characteristics of locust bean pods ash with coarser-grained soil with respect to the soil mineralogy for the purpose of subgrade of pavements. Furthermore, the study also examined the possibility of considering the use of the duo materials as foundation soil by evaluating their shear strength parameters.

2.0 MATERIALS AND METHODS

This study was on a lateritic soil deposit at Nung Oku in Ibesikpo Local Government Area of Akwa Ibom State, with coordinates of latitude 4.95ºN and longitude 7.92ºE. The soil sample was obtained at a depth of 1.5m with disturbed sampling technique and was then air dried. The locust bean pods used were also sourced from Ibesikpo Local Government Area of Akwa Ibom State in Nigeria. The locust bean pods were prepared by drying and incinerating them to ash in a furnace at a temperature of 600ºC. Then the locust bean pods ash was allowed to cool, ground thoroughly and sieved through 75µm sieve as stipulated by BSI 12 [29]. The resulting filtrate was then used for this study. The determination of the oxides contained in locust bean pods ash (LBPA) was achieved using the Atomic Absorption Spectrometer. The X-ray diffraction technique was used to find out the compositions of the minerals present in the soil sample. The treated soil samples were prepared by first thoroughly mixing the locust bean pods ash (LBPA) and lateritic soil dry until a uniform mixture was achieved before water would be added. The doses of locust bean pod ash used in the mixes ranged from 0% to 25% at 5% intervals, measured as a percentage of the dry soil. The tests conducted on the natural soil samples and soil-LBPA mixtures were executed in accordance with ASTM D4318-10 [30], ASTM D6913-17 [31] and BSI 1377 [32].

For consistency indices, the samples to be tested underwent initial sieving through a 425µm sieve prior to testing. The liquid limit testing was conducted using the Casagrande apparatus, with the liquid limit defined as the water content at which 25 bumps of the Casagrande apparatus closed a groove of approximately 13mm. Meanwhile, the plastic limit was determined as the water content at which a thread-like sample, about 3mm in diameter, rolled with the palm just developed a crack. Samples for the specific gravity were prepared using the density bottle. The sample for particle size distribution was first washed on sieve No 200 (75µm) and oven-dried. Following this, the sample underwent sieving using a set of stack sieves ranging from 4.75mm to 0.075mm. The compaction test was conducted using the British Standard Light method, wherein specimens were prepared using the Standard Proctor mold, approximately 1000 cm^3 in volume, and compacted using a 2.5 kg rammer. The samples were prepared in 3 layers in the mould and 27 blows were given onto each layer to determine the optimum moisture contents and the maximum dry densities. The California Bearing Ratio test was conducted with specimens which were prepared in 5 layers, 2.5 kg rammer was used as the compaction effort and each layer received 56 blows. Predetermined water contents obtained from moisture-density relationships were used to prepare the specimens. Samples of the soil mixtures designated for the direct shear test were utilized to fill the shear box, generating specimens that were thoroughly tamped and then subjected to varying applied normal stresses to achieve consolidation. The corresponding shear stresses at failure during the shearing stages were recorded and after which the shear strength envelopes were obtained to determine the shear strength parameters (cohesion and angle of internal friction).

3.0 RESULTS AND DISCUSSION

This section contains the results obtained from the experiments and the analysis. The results were broken down into subsections as follows

3.1. Characterization of Locust Bean Pods Ash (LBPA)

Table 1 Chemical Components of Locust Bean Pod Ash

Chemical Constituent	Percentage Composition (%)
Sodium Oxide (Na_2O)	1.42
Potassium Oxide (K_2O)	8.07
Magnesium Oxide (MgO)	2.28
Lead Oxide (Pb_2O_5)	1.04
Iron Oxide (Fe_2O_3)	10.06
Aluminium Oxide (Al_2O_3)	15.13
Calcium Oxide (CaO)	13.02
Silicon Oxide (SiO_2)	43.20
Loss on Ignition (LOI)	5.71

Table 1 presents the chemical constituents of Locust bean pods ash (LBPA) which confirms that LBPA consists mainly of Silicon Oxide (43.20%), Calcium Oxide (13.02%), Aluminium Oxide (15.13%), Iron Oxide (10.06%), Lead Oxide (1.04%) and Potassium Oxide (8.07%) with traces of Magnesium Oxide (2.28%) and Sodium Oxide (1.42%). LBPA also exhibits a significant presence of organic matters due to the loss on ignition is quite high. It is required that for a mineral admixture to be regarded as a suitable pozzolanic material, it must possess SiO_2 + Al_2O_3 + Fe_2O_3 a minimum of 70% and SO_3 a maximum of 4% [33]. Considering the chemical contents of LBPA in Table 4.1, SiO_2 + Al_2O_3 + Fe_2O_3 is 68.39% which marginally fell short of the foregoing standard while the absence of SO_3 is very favourable. Consequently, LBPA could be regarded as a suitable pozzolanic material. It is also pertinent to note that LBPA also contains significant amounts of other compounds like Calcium Oxide (13.02%) and Potassium Oxide (8.07%) which also exhibit cementitious properties. The specific gravity of LBPA is 1.35.

3.2. Findings on the Characteristics of Natural Soil

Table 2 presents the geotechnical characteristics of the lateritic soil in its natural state while Figure 3 is the particle size distribution curve. Based on the sieve analysis test, the Unified Soil Classification System (USCS) [34] classified soil based on the grading of the grain sizes especially for coarse-grained soil when the percentage passing sieve No 200 (75 µm aperture size) was very little (2.00%). The soil was rated to be coarse-grained (sand) because greater percentage of the soil was found between Sieve number 4 and 200. From the particle sizes distribution, the coefficient of uniformity, Cu, was found to be 0.111. The USCS [34] stipulates that soils with coefficient of uniformity less than four, are regarded to be poorly graded soils. Therefore, since the coefficient of uniformity was less than 4, the lateritic soil can be graded as poor. The USCS [34] further categorizes soils with a coefficient of curvature (Cc) less than 1 as poorly graded. Therefore, based on the coefficient of curvature value, which was derived from the particle size distribution and found to be 0.241, it reconfimed that the classification of the lateritic soil as poorly graded since the coefficient of curvature is less than 1. According to the AASHTO soil classification system [35], the soil is classified as belonging to the A-2-6(0) group soils. The position of the soil group in the AASHTO soil classification Table [35] suggests that it is fairly suitable as a sub-grade material. This is because the farther to the right the soil group is on the table, the poorer it is for construction work. In this case, the soil group appeared to be positioned more to the left on the AASHTO soil classification Table [35], indicating better suitability for construction purposes. Furthermore, the group index (GI) in parenthesis indicated a zero value for the lateritic soil, which is highly satisfactory as lower values denote better soil quality. However, according to F.M.W.H. [36], the specified value for the California Bearing Ratio (CBR) of sub-grade materials should be 15%. However, the lateritic soil fell short in CBR value, recording only 11.5%.

Table 2 Geotechnical Characteristics of the Natural Lateritic Soil

Soil Property	Description
Colour	Reddish-brown
Natural Moisture Content	18.42%
Specific Gravity	2.45
Liquid Limit	37.00%
Plastic Limit	23.21%
Plasticity Index	13.79%
Percentage Passing Sieve No 200 (75µm)	2.00%
Coefficient of Uniformity, Cu	0.111
Coefficient of Curvature, Cc	0.241
AASHTO (2011) Classification System	A-2-6(0)
USCS Classification System, ASTM D2487 (2017)	Poorly Graded Sand (SP)
Optimum Moisture Content	11.00%
Maximum Dry Density	1.95g/cm^3
California Bearing Ratio	11.5%
Cohesion	20.396 kN/m^2
Angle of Internal Friction (Ø)	40.75º

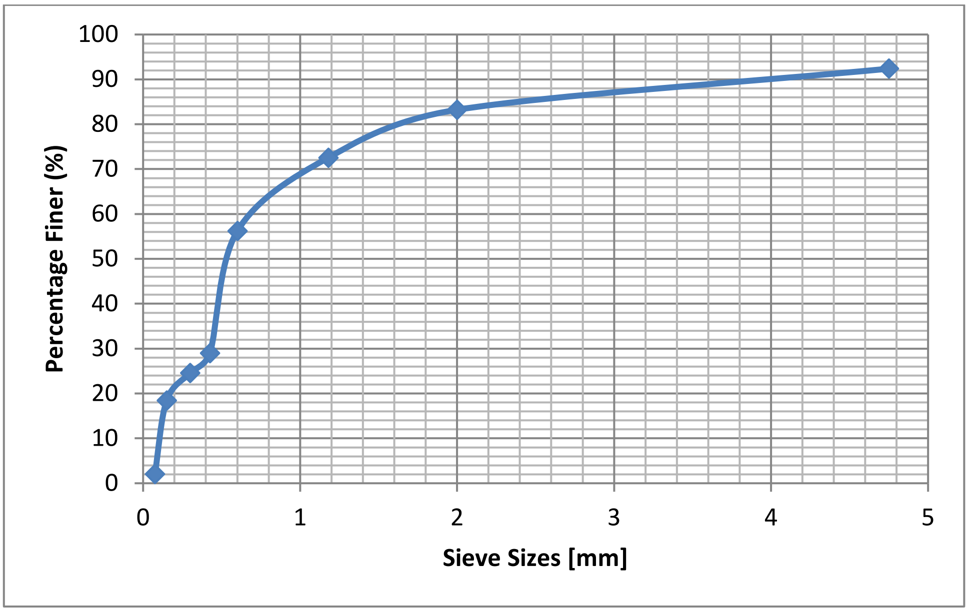

Figure 3 Particle size distribution curve

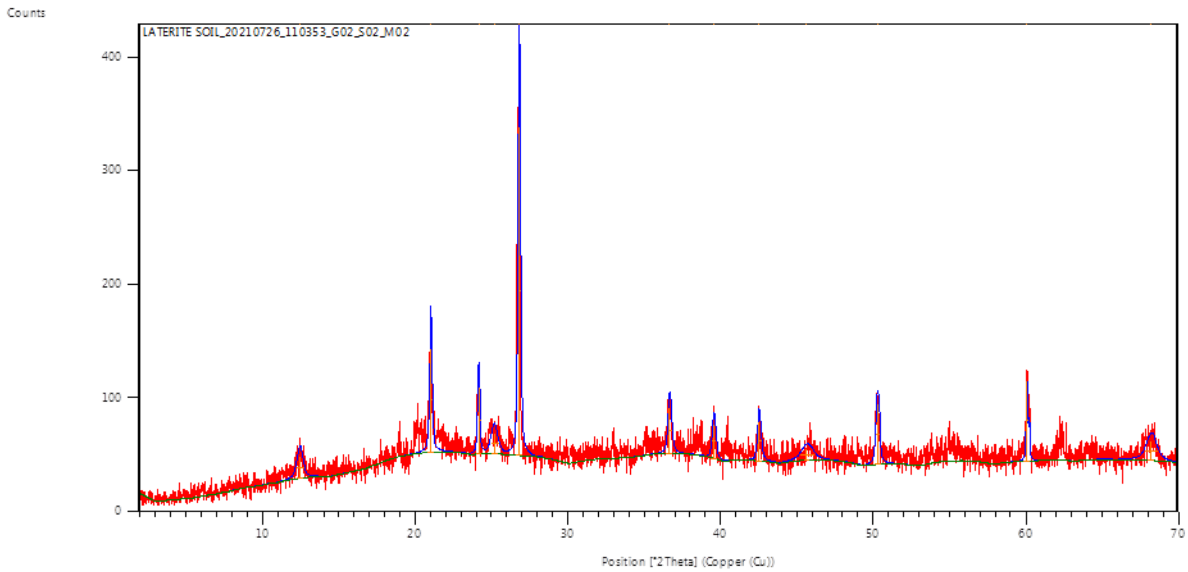

Figure 4 Pictorial view of the intensities of X-ray diffraction on the natural soil

Figure 4 and Table 3 are the pictorial view and analysis respectively of the X-ray diffraction intensities on the natural soil. The identification and quantitative presence of soil minerals were achieved using the spacing of the atomic planes (d) measured in Angstroms (Å). The values in Angstroms (Å) of 7.11322, 4.22638, 3.68562, 3.53811, 3.32550, 2.45108, 2.27765, 2.12535, 1.98689, 1.81517, 1.54032 and 1.37538 indicate the presence of kaolinite, quartz , feldspar, carbonate/chlorite, illite, chlorite, quartz, quartz/mica, kaolinite, quartz, vermiculite and quartz/chlorite respectively [35]. The non-clay minerals in the soil are quartz, feldspar and mica. Quartz is rich in silica (SiO_2) with hexagonal crystal system and absence of cleavage. The particle shape is bulky, specific gravity of 2.65 and hardness of 7 [36]. Feldspar can exhibit variations, either as Sodium Aluminium Silicate (Plagioclase) or Potassium Aluminium Silicate (Orthoclase). Its crystal system spans from monoclinic to triclinic, with cleavage occurring along two planes, and its particle shape tends to be bulky-elongate. The specific gravity is 2.62 – 2.76 and the hardness is 6 [36]. The engineering behaviour of the soil is mainly affected the clay minerals present in the soil. The major clay minerals present in the soil are kaolinite, illite, vermiculite and chlorite. The kaolinite mineral is composed of alternating layers of silica and octahedral sheets. The di-octahedral

Table 3 Analysis of X-ray Diffraction Intensities on the Natural Soil

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
12.4440	19.20	0.4723	7.11322	6.64
21.0204	91.24	0.1968	4.22638	31.54
24.1479	59.44	0.1574	3.68562	20.54
25.1709	17.92	0.4723	3.53811	6.19
26.8092	289.30	0.1574	3.32550	100.00
36.6649	40.43	0.2362	2.45108	13.98
39.5685	30.66	0.2362	2.27765	10.60
42.5365	34.86	0.2362	2.12535	12.05
45.6616	9.86	0.9446	1.98689	3.41
50.2657	53.01	0.2362	1.81517	18.32
60.0668	70.80	0.1181	1.54032	24.47
68.1847	16.96	0.7872	1.37538	5.86

sheets alternating gibbsite layers are common in clay minerals in the kaolinite subgroup. The structural formular is $(OH)_8Si_4Al_4O_{10}$ [37]. The Van der Waals forces and hydrogen bonds between two successive layers of kaolinite are exceptionally strong, preventing interlayer swelling when the soil comes in contact with moisture. The isomorphous substitution between the structures of kaolinite minerals is very small and the cation exchange capacity is 3 to 15 meq/100g which indicates inactive clay mineral. The illite clay mineral is composed of an octahedral layer of gibbsite sandwiched between two layers of silica tetrahedral layer in a 1:2 arrangement [39]. Some of the silica positions within the illite clay mineral structure are occupied by aluminum atoms, and potassium ions are situated between the layers to compensate for the resulting charge deficiency. The bonding in illite results in a less stable condition compared to kaolinite, leading to higher activity of the illite mineral. Consequently, this higher activity contributes to greater volume changes of the soil in the presence of water. The cation exchange capacity of illite is 10 – 40 meq/100g. Vermiculite is a clay mineral within the illite family, sharing similarities with illite except for a double molecular layer of water between sheets interspersed with calcium and/or magnesium ions, and the substitution of brucite for gibbsite in the octahedral layer. The cation exchange capacity of vermiculite typically ranges from 100 to 150 meq/100g. The Chlorite structure consists of mica-like and brucite-like layers. The structure is similar to that of vermiculite, except that an organized octahedral sheet replaces the double water layer between mica layers. The cation exchange capacity is 10 – 40 meq/100g.

3.3. Geotechnical Properties of Soil-Locust Bean Pod Ash Mixtures

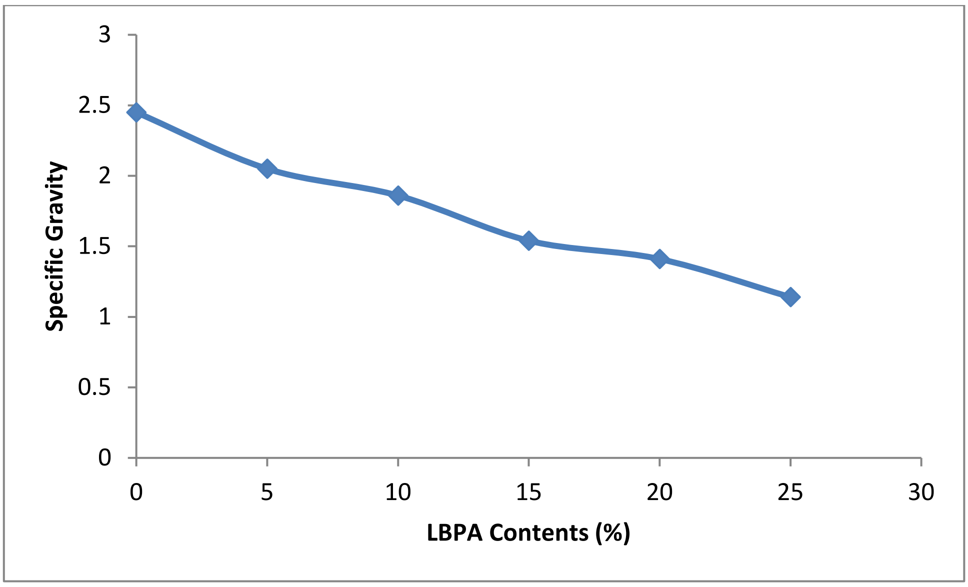

Figure 5 Variation of specific gravity with the increase in LBPA contents

The relationship between specific gravity and locust bean pods ash (LBPA) content was shown in Figure **5**. The specific gravity reduced from 2.45 – 1.14 with the increase of LBPA content from 0- 25%. The specific gravity test results revealed that the natural soil had a specific gravity of 2.45, whereas locust bean pod ash (LBSA) alone exhibited a specific gravity of 1.35. The reduction trend was as a result of the continuous partial replacement of the lateritic soil of higher density by LBPA with lower density which consequently reduced the specific gravity. Lower specific gravity indicates a coarse soil, while higher specific gravity indicates a fine-grained soil . It is specified that materials intended for use as subgrade for roads and bridges should have a specific gravity of at least 2.2 [38]. The soil has a specific gravity of 2.45 which met the requirement for use as a subgrade although there should be a trade-off balance between specific gravity and other vital geotechnical properties.

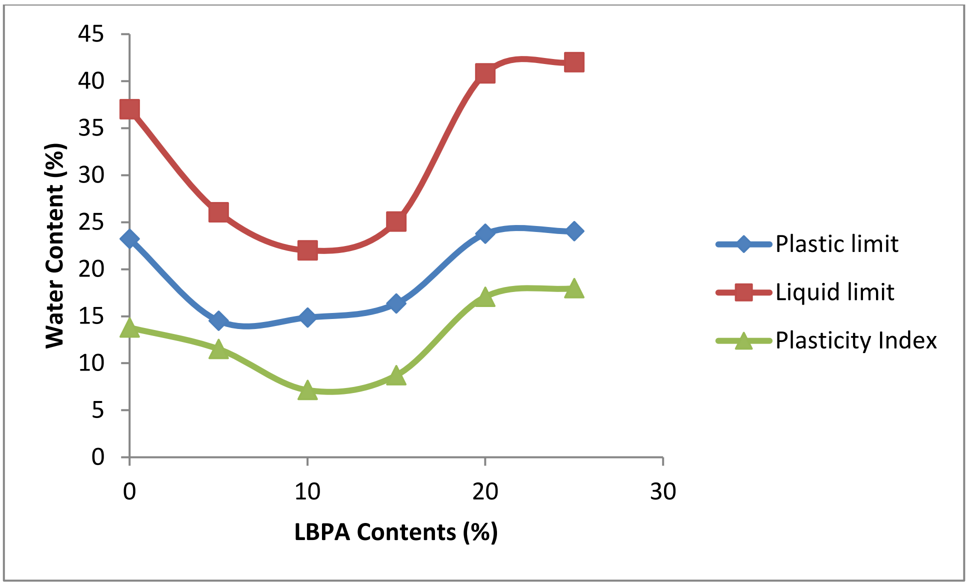

Figure 6 Variations of consistency indices with the increase in locust bean pod ash contents

Figure 6 depicts the variations in consistency indices with an increase in LBPA contents. As LBPA contents increased from 0% to 10%, the water content decreased from 37.00% to 22.00% for liquid limit and from 23.21% to 14.86% for plastic limit, respectively. These initial drops in water content represent the requirements to attain the liquid limit (the water content at which the mixture behaves like a fluid) and the plastic limit (the water content at which a cylindrical specimen of approximately 3mm diameter crumbles), aligning with the findings of Daha et al. [25] and Adama et al. [26]. This trend of results could be attributed to LBPA gradually replacing the major clay minerals present in the soil, particularly illite, vermiculite, and chlorite, as indicated by the X-ray diffraction results in Table 3. These clay minerals are of medium activity and have a higher affinity for water than the LBPA particles. As a result, the soil-LBPA mixture reached the consistency limits at lower water contents. However, there was a sharp increase in water content requirements for the consistency limits, with values rising from 25.055% to 42.00% for the liquid limit and from 16.35% to 24.03% for the plastic limit, respectively, at LBPA contents ranging from 15% to 25%. The foregoing could be attributed to the continuous increase in LBPA contents, which led to a sharp increase in the amount of fine particles present in the soil-LBPA mixtures as consistency limits are primarily influenced by the finer particles in the soil. Therefore, as the LBPA content increased, more water was needed to bring these mixtures to their liquid and plastic limits. Concerning the plasticity indices, there was a corresponding decrease in water content from 13.79% to 7.14% with LBPA contents ranging from 0% to 10%, and higher water content values of 8.71% to 17.97% at LBPA contents between 15% and 25%. The plasticity index represents the range of water content at which the soil-LBPA mixtures exhibit plastic behaviour, and it is determined by the difference between the liquid limit and plastic limit. Therefore, the reasons previously outlined for the behavior trends of the soil-LBPA mixtures concerning liquid and plastic limits would also apply to plasticity indices.

Table 4 shows the variations in compaction characteristics as the LBPA contents increased. The optimum moisture content increased from 11 – 13.67% as the LBPA contents increased from 0 - 25%. The results were in agreement with that of Daha *et al.*[25] and Adama *et al.*[27] but contrary to Ige and Oyeniyan [26]. The increase in optimum moisture content could be attributed to the continuous rise in the material content of the mixture. With increasing LBPA contents, more water was needed to sufficiently lubricate the soil-LBPA particles. Consequently, the optimum moisture content showed a continuous increase. As a result, the maximum dry density decreased from 1.95 g/cm3 to 1.60 g/cm3 with the increase in LBPA contents from 0% to 25%, which is consistent with the findings of Daha *et al.* [25], Adama *et al.* [26], as well as Ige and Oyeniyan [27]. The reduction in the maximum dry density could also be linked to the reduction of the specific gravity of the soil-LBPA mixtures. Hence, the lower specific gravity of the soil-LBSA mixtures would result in lower density. According to F.M.W.H [36] specifications, materials intended for use in the construction of roads and bridges must have an optimum moisture content of less than 18% and a maximum dry density greater than 0.047g/cm3, both of which the materials satisfied.

Table 4 Variations of Compaction Characteristics with Changes in Locust Bean Pods Ash Contents

	LBPA Contents					
	0%	5%	10%	15%	20%	25%
Optimum Moisture Content (%)	11	11.62	12.2	12.4	13.52	13.67
Maximum Dry Density (g/cm^3)	1.95	1.93	1.80	1.74	1.63	1.60

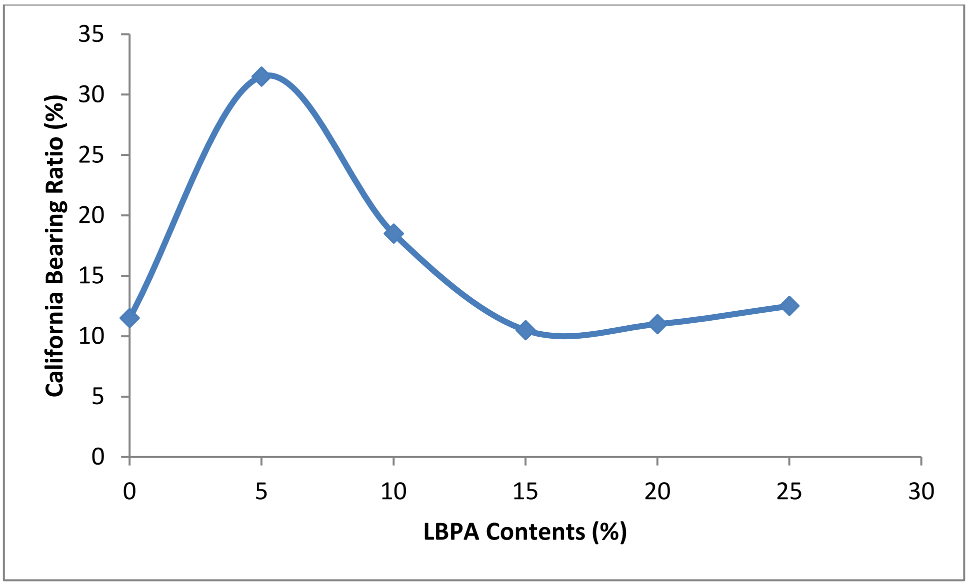

Figure 7 Variations of California Bearing Ratio with the increase in locust bean pod ash contents

California Bearing Ratio is a measure of strength characteristics by penetration. Figure 7 is a graphical representation of the variations of California Bearing Ratio with the increase in LBPA contents. The California Bearing Ratio increased from 11.50% to 31.50% with the addition of 5% LBPA but subsequently decreased to 12.50% with further increases in LBPA contents up to 25%. The results of Daha *et al.*[25] similarly showed an initial increase in California Bearing Ratio, followed by a reduction at a content of 9% of the admixture. Based on the X-ray diffraction test results for the soil presented in Table 3, it was revealed that the soil was rich in quartz, one of the major non-clay minerals containing a high amount of Silicon Oxide. Additionally, LBPA was found to contain significant amounts of Calcium Oxide, Aluminum Oxide, Iron Oxide, and Silicon Oxide, as shown in Table 3. Hence, the initial increase in the California Bearing Ratio value could be attributed to the reaction of certain amounts of Calcium Oxide with Silicon Oxide, Aluminum Oxide, and Iron Oxide present in both the soil and LBPA, in the presence of water. This reaction leads to the formation of significant quantities of cementitious compounds, such as hydrates of Calcium Silicate and Calcium Alumino Ferrites. The equations for the chemical reactions are shown in Equation 1 to Equation 3. Subsequently at the further increase in LBPA contents, the California Bearing Ratio plummeted because the LBPA content exceeded the optimal level for strength improvement. It is specified that the California Bearing Ratio (CBR) for sub-grade materials should be at least 15% [36]. With a 5% addition of LBSA, the soil achieved the highest CBR value of 31.50%, surpassing the required 15%.

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 + SiO_2 \rightarrow CaO.SiO_2.H_2O \quad (2)$$

$$Ca(OH)_2 + Al_2O_3 + Fe_2O_3 \rightarrow CaO.Al_2O_3.Fe_2O_3.H_2O \quad (3)$$

Table 5 Variations in Shear Strength Parameters with the Increase in Locust Bean Pod Ash Contents

	LBPA Contents					
	0%	5%	10%	15%	20%	25%
Cohesion (kN/m^2)	20.396	19.230	20.149	18.770	15.058	5.116
Angle of Internal friction	40.73°	40.28°	39.35°	37.06°	32.26°	27.49°

Table 5 shows the variations of the shear strength parameters of the soil as the LBPA contents increased. The cohesion of the soil dropped from 20.396 – 5.116 kN/m^2 while the angle of internal friction reduced from 40.73° - 27.49° as the LBPA content increased from 0 - 25%. Cohesion is the measure of a soil's resistance to shear stress, resulting from the interlocking of clay particles within the soil. The reduction trend in cohesion at the addition of LBPA could be attributed to the gradual replacement of clay particles in the soil by LBPA which resulted in a continuous reduction in cohesion of the soil. The natural soil had a higher soil cohesion and angle of internal friction which indicated that it had the highest shear strength. This shows that the addition of LBPA weakened the shear strength of the soil, the most important property of the foundation soil. Hence, it can be concluded that LBPA is not suitable for soil to be used in the foundations of structures.

To be deemed as a suitable sub-grade material, F.M.W.H. [38] stipulated that the specific gravity should not be less than 2.2, the liquid limit should be less than or equal to 40%, the plasticity index should be less than or equal to 20%, the optimum moisture content should be less than 18%, the maximum dry density should be greater than 0.047g/cm^3 and the California Bearing Ratio should be greater than 15%. Based on the F.M.W.H. [38] standards, 5% LBPA content is the optimum amount of treatment for the soil because it is the most suitable for subgrade material judging by its geotechnical characteristics considering its value of 26.03%, 11.51%, 11.62% and 1.93 g/cm^3 for the liquid limit, plasticity index, optimum moisture content and maximum dry density, respectively. While it marginally fell-short in specific gravity requirement, it is acceptable because in road construction work, the strength property requirements out-weigh the specific gravity requirement. The soil treated with 5% LBPA content exhibited a higher California Bearing Ratio value of 31.5%, surpassing the required threshold of 15%. In contrast, the untreated natural soil had a lower value of 11.5%, failing to meet the specified requirement.

4.0 CONCLUSIONS

Based on the results of the current research, the following conclusions were made:

I. The LBPA was deemed to be an acceptable pozzolanic material for the treatment of the lateritic soil.

II. The lateritic soil was classified to belong to A-2-6(0) group of soils in the AASHTO [39] rating and a poorly graded sand (SP) in USCS [34] rating.

III. It was found that the non-clay minerals found in the soil were quartz, feldspar and mica while the clay minerals were kaolinite, iolite, vermiculite and chlorite.

IV. The specific gravity of LBPA was quite small and the additions of LBPA reduced the specific gravity of the soil.

V. The consistency indices dropped with the addition of LBPA up to 10% content but subsequently increased with further addition of LBPA.

VI. As the LBPA content increased, the optimum moisture content also increased, while the maximum dry density decreased.

VII. The increase in LBPA content decreased the shear strength parameters of the lateritic soil (cohesion and angle of internal friction)

VIII. The strength characteristics, such as the California Bearing Ratio, of the lateritic soil improved by 173.91% with the addition of 5% LBPA content. However, they subsequently reduced further with increments in LBPA content.

Conflicts of Interest

The authors unequivocally state that there is no competing interest in this article. There is non-financial interest or any funding institution. The authors wish to state without any reservation that this article is original from us and has not been published in part or whole in any publishing house. We also assure that all the data presented in this article can be supplied through the corresponding author on reasonable request.

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