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EFFECTS OF LOCUST BEAN (*PARKIA BIGLOBOSA*) POD EXTRACT ON THE CONSISTENCY LIMITS OF MARGINAL SOILS FOR ROAD PAVEMENT LAYER CONSTRUCTION

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ABSTRACT

Earthworks in road pavement layer construction present huge challenges with severe financial implications especially when suitable material for base course and subbase course are not found along the road corridor or within reasonable haulage distances. In most cases, it may be easy to find marginal materials or materials that need some form of stabilization. Chemical and mechanical stabilization is common but could be expensive. Plant extracts for stabilization hold promise but more research is required to identify locally available plants that can be cultivated or applied at scale if found useful. In this exploratory study, the potential effects of stabilization of marginal lateritic gravel soils using locust bean pod extract (LBPE) were studied for Consistency Limits of natural gravel materials for road pavement layer construction. The extract was prepared by pounding and soaking the locust bean pods in tap water for intervals of up to 28 days. The soil sample was obtained from Agyei-Ano South, Sunyani, and tested in the geotechnical laboratory of Sunyani Technical University (STU). The soil was analyzed for index properties and classified as Silt-Clay material (A-6(5)) and clayey gravels (GC) using the AASHTO and Unified Soil Classification Systems respectively. Consistency limit tests for the control and test specimens were determined using distilled water and LBPE respectively. The soils stabilized with LBPE were found to generally exhibit 3.5% – 7.1% higher Liquid Limit (LL), and 0.9% – 15.0% higher Plastic Limit (PL) than the control. Compared with the control, the Plasticity Index (PI) values were lower by up to 22 %. Lower PI is desirable in road construction materials. Improvements of up to 20.2% in the Consistency Index and up to 55 % in the liquidity index of the LBPE samples over the control were observed. This is an indication that LBPE could improve the engineering properties and change the classification of the lateritic soil, in this instance, from G30 grading envelope plasticity index requirement to the G40 grading envelope plasticity index requirement. The optimum soaking duration was found to be 3 days.

Key Words: Locust bean pod extract; liquid limit; plasticity index; consistency index; chemical stabilization.

INTRODUCTION

In Sub Saharan African countries, gravel and earth surfaced roads constitute the majority of the road network size including main or trunk roads. Unpaved roads also exist in developed countries, for instance in the USA, there are about 2.6 million kilometres of unpaved roads, most of which are classified as gravel roads or low volume roads (Mishra and Tutumluer, 2012). In Ghana, for instance, the total road network size as of 2020 is 78,401km, of which gravel roads form about 83% of the road network (Ministry of Roads & Highways, 2021). The Department of Feeder Roads (DFR) has a total network of 48,357km representing about 62% of the total road network in Ghana (Ministry of Roads & Highways, 2021). However, according to the annual report of the year 2022, DFR has only 9% of the road network paved, leaving the rest 91% as gravel and earth roads (Department of Feeder Roads, 2023). This does not include unpaved trunk and urban roads.

Among many developing nations around the globe, the road network is predominantly gravel-surfaced (Oloo *et al.*, 2003). According to Wilkie *et al.* (2000), this network makes up the farm-to-market roads and therefore very vital to any nation's economy. Because of the important role that gravel roads play in any nation's economy, they must be properly maintained to ensure their sustainable contribution to the economy. Excluding roads under construction and missing links, the trunk roads network in Ghana consists of about 57% paved and 35%, unpaved including roads classified as inter-regional roads and some sections of National roads (Ghana Highway Authority, 2023). Several unpaved roads have subbase quality gravel or do not have any gravel left and driving is on subgrade. There are also engineered and un-engineered unpaved roads.

One major problem facing the maintenance of lateritic gravel roads, which makes it relatively expensive and unsustainable is the loss of fines (clay) from the gravel surface of the road in the form of dust or particulate matter. For these surfaces, the fines act as the cementing material that binds the coarse particles together to provide a relatively impermeable barrier to the ingress of water. During the dry season, the stresses generated by the continuous movement of vehicles on the roads loosen these bonds and separate the gravel-sized particles from the fines. The fines (dust) may then escape into the atmosphere or onto nearby plants blocking their stomata in the process or onto surfaces of monuments and houses causing nuisance and health problems. Due to the loss of fines, the unpaved roads deteriorate more quickly, increasing therefore cost of maintenance required to keep the road in an accessible or usable condition. This also increases the particulate matter PM 2.5 in the atmosphere surrounding the road leading to health consequences (Ajayi *et al*., 2023). Apart from the increase in the work rate and cost involved in the maintenance of the roads, because of the loss of fines, there is also the added environmental pollution caused by the lost fines (dust) that is released into the environment. Health problems in addition to the nuisance caused by the dust are problems that need serious studies to provide solutions readily accessible and at optimum cost in the rural areas.

Road pavement layer construction employs the use of soil as the main construction material. The amount of work to be done in terms of earth movement is always a challenge when suitable material such as basecourse and subbase course material is not found along the road corridor or within reasonable haulage distance. This issue compels one to improve upon the soil properties found along the road corridor to reduce costs. Stabilization of available marginal materials within the road corridor with chemicals or mechanical stabilization has been tried with some success but plant-based extract approach has not been tested. To explore plant-based extract, candidate plants with adequate potential must be identified, their efficacy tested and their scalability assessed. Given these problems, there is the need to find suitable ways to improve upon these materials which fail to meet the requirements of base course and sub-base course material specifications. This will bring about a reduction in the cost of hauling materials over a long distance and by extension road construction projects in the country.

Industrial and agricultural activities are on the increase, giving rise to a significant increase in industrial and agricultural wastes, which most often have impacted negatively on the environment. Across the globe, many research efforts in recent times are geared towards possible ways of recycling these wastes for reuse to keep the environment clean and safe (Adama and Jimoh, 2012). The transportation, construction and environmental industries have the greatest potential to recycle these large quantities of waste, (Basha *et al.*, 2003). Using agricultural wastes in soil stabilization serves the dual purpose of protecting the environment, and improving the geotechnical properties of previously unsuitable materials for construction work. Many authors have studied the stabilization potential of the ashes of agricultural wastes including the locust bean pod and rice husk (Okafor and Okonkwo, 2009; Adama and Jimoh, 2012; Adama *et al.*, 2013; Osinubi *et al.*, 2016). A few authors have also studied the use of the locust bean pod extract on production of landcrete and sandcrete blocks for building (Aguwa and Okafor, 2012; Aguwa *et al.*, 2016). However, a literature search has yielded no research publications on the use of locust bean pod extract for the stabilization of road pavement layer materials. This study explores the outcomes of the extract from the locust bean pod directly on the Atterberg limits of marginal lateritic soils for road pavement layer construction.

The Locust Bean Pod Extract (LBPE) produced from soaking the locust bean pod in water could offer a less expensive product to stabilize marginal soils to meet standard specifications for use as subbase and base material. This paper examines the potential properties of stabilized marginal lateritic gravel soils using locust bean pod extract (LBPE) for road construction. The locust bean pod is a Waste Agricultural Biomass (WAB) obtained from the fruit of the African locust bean tree. The harvested fruits are ripped open to obtain the pods while the yellowish pulp and seeds are removed from the pods. The pods make up 39% of the weight of the fruits while the mealy yellowish pulp and seeds make up 61% (Adama and Jimoh, 2012). The material resources required for the production of Locust Bean Pod Extract (LBPE) is the husk or pods and water. Further studies are currently on-going to determine the chemical constituents of the LBPE.

MATERIALS AND METHODS

The following materials, tools and equipment were employed in this research work.

Materials

Soil Sample

The soil sample (figure 1 below) used in this research was collected from Agyei-Ano South within the Sunyani Municipality of the Bono Region of Ghana. The soil sample was collected during the rainy season. The soil was reddish brown in colour typical of lateritic soils rich in iron III oxide. The soil sample was then allowed to air dry in the Sunyani Technical University materials laboratory, before using it to conduct the required tests.

Figure 1: Air drying of Soil Sample

Locust Bean Pod

The Locust Bean Pods used in this study were obtained from Tongo in the Upper East Region of Ghana. The pods are usually available as a waste product of agricultural processing of the locust bean fruits during the harvest season. The pods were pounded to reduce them into smaller sizes before soaking them to produce the extract as shown in figure 2. A weighed quantity of the pounded locust bean pod was completely soaked in water for varying periods in days.

Figure 2: Pounded Locust Bean Pods.

Other Materials

Other materials used in this research include tap water, distilled water, Sodium hexametaphosphate and Hydrogen Peroxide

Methods

Extraction Procedures for LBPE

The locust bean pods were first pounded into a mixture of powder and broken-down pods using a wooden mortar and pestle. The wooden mortar and pestle were used to pound the locust bean pod to finer particle sizes to ensure effective extraction.

A mass of 550 grams of pounded LBP was weighed and soaked in 5.5 liters of tap water that was free from contaminants for one day. Water was identified as the best solvent for the extraction (Abagale *et al.*, 2013). The solution was sieved on the 0.075mm sieve size to obtain the one-day duration extract. The procedure was repeated for the various durations of soaking to obtain the 2-days, 3-days, 4-days, 5-days, 7-days, 14-days, 21-days and 28-days duration extracts respectively.

Particle Size Determination of the Coarse fraction of Control Specimen

Wet sieving was performed on the natural soil. Three (3) liters of water containing dissolved sodium hexametaphosphate, a dispersing agent, was added to the soil specimen and the specimen stirred for one (1) hour before washing in order to completely separate the fine particles in the soil. Every one (1) liter of water contained two (2) grams of the sodium hexametaphosphate dissolved in it. The soil specimen was then oven-dried for twenty (24) hours before using it for the sieve analysis. The sieve sizes were arranged in ascending order, starting from the lowest sieve size at the bottom to the highest sieve size at the top. The soil was then poured into the top sieve and a lid was placed on the top sieve. The set of sieves were shaken for five (5) minutes using a mechanical shaker. The sieves were separated and the mass of the soil retained on each sieve was determined for further analysis. The test was performed according to BS 1377 1990 Part 2 (British Standards Institution, 1990).

Sedimentation Analysis of the Fine Fraction of Control Specimen

Hydrometer test was also conducted on the fine particles, that is the soil that passes through the sieve size 75µm to the pan. Fifty (50)g of the soil passing the 75µm sieve size was taken to perform the test and 100ml of sodium hexametaphosphate solution was added to the soil specimen. The soil specimen was then stirred for four (4) hours before adding it to the 1000ml measuring cylinder. Distilled water was added to reach the 1000 ml graduation and the hydrometer readings taken at predetermined time intervals. The test was performed according to BS 1377 1990 Part 2 (British Standards Institution, 1990).

Determination of the Consistency Limits of the Control Specimen

Sample Preparation

The test specimen was prepared according to BS 1377 1990 Part 1 (British Standards Institution, 1990). Due to the unavailability of 0.425mm sieve size, the material was sieve through the 0.5mm sieve size. A weight of 220 grams of the test specimen was obtained and placed on the Perspex plate. Using distilled water, the sample was mixed thoroughly into a thick homogeneous paste, and stored in an air tight container for 24 hours before performing the test. After 24 hours, the specimen was remixed and divided into two parts 70% and 30%. The 70% - part was used for liquid limit determination and 30% part was set aside for plastic limit determination.

Liquid Limit Determination

Using two spatulas and by adding reasonable amount of the distilled water, the specimen for liquid limit determination was thoroughly remixed for at least 10 minutes. The test was carried out according to BS 1377 1990 Part 2 (British Standards Institution, 1990). Since the cone penetrometer was made after the Chinese standard, the Liquid limit was determined at a cone penetration of 17mm.

Plastic Limit Determination

The 30% - part specimen set aside for plastic limit determination was molded and remixed until it is plastic enough to be shaped into a ball without sticking to the fingers. The specimen was molded into a ball between the fingers and rolled between the palms of the hands until slight cracks appear on the surface. Molding and kneading were necessary throughout the test to preserve a uniform distribution of moisture and to prevent excessive drying of the surface only. The specimen was rolled into a rod about 3mm in thickness and placed in moisture content containers. The test was carried out according to BS 1377 1990 Part 2 (British Standards Institution, 1990).

Determination of Consistency Limits of the Test Specimens

Sample Preparation

The test specimen was prepared according to BS 1377 1990 Part 1 (British Standards Institution, 1990). However, for the test specimens, LBPE was used to thoroughly mix the soil sample into a thick homogeneous paste, before it was stored in an air tight container for 24 hours.

Liquid Limit Determination

The procedure for Liquid limit determination for the control specimen was followed but LBPE was used in place of distilled water for the test specimens. The test was carried out according to BS 1377 1990 Part 2 (British Standards Institution, 1990). The procedure was repeated for all the various soaked durations of the extract to determine the liquid limit values of the soil for each extract.

Plastic Limit Determination

The procedure for Plastic limit determination for the control specimen was followed but LBPE was used in place of distilled water for the test specimens. The test was carried out according to BS 1377 1990 Part 2 (British Standards Institution, 1990). The procedure was repeated for all the various soaked durations of the extract to determine the liquid limit of the soil for each extract.

RESULTS AND DISCUSSION

Particle Size Distribution of Control (Natural Soil)

The results of both the grading test and hydrometer test are presented in Table 1.

Table 1: Particle Size Distribution

Sieve Size (mm)	% Passing	Sieve Size (mm)	% Passing	Sieve Size (mm)	% Passing
60.00	100.00	0.0750	48.62	0.0054	20.05
40.00	100.00	0.0621	40.14	0.0047	19.23
20.00	92.65	0.0449	37.80	0.0034	16.80
10.00	80.82	0.0324	35.46	0.0024	14.99
5.00	67.42	0.0213	30.77	0.0018	13.23
2.00	59.16	0.0155	27.65	0.0016	12.61
1.00	58.12	0.0111	25.39	0.0014	12.28
0.5000	56.37	0.0092	23.91	0.0013	11.25
0.2500	52.56	0.0075	22.39	0.0011	10.47
0.1500	50.81	0.0066	21.45	0.0007	8.55

The particle size distribution curve is presented in Figure 3. The soil was approximately made up of 14% clay (less than 0.002mm), 26% silt (0.002mm – 0.06mm), 20% sand (0.06mm – 2mm) and 40% gravel (greater than 2mm).

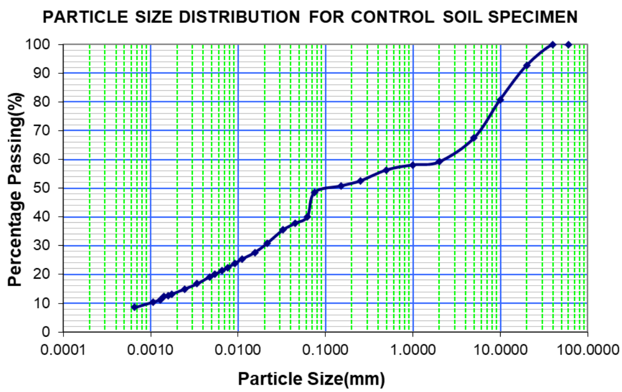

Figure 3: Particle Size Distribution Curve for the Control

Liquid and Plastic Limit of the Control

The liquid limit of the control specimen was found to be 38.25% and the plastic limit was also found to be 22.44%. Thus, the Plasticity Index was 15.81%.

Classification of the Control

The results of the index property tests on the control as afore presented help to classify the soil using both the unified soil classification system (USCS) and the AASHTO classification system. From the results, the grading characteristics can be determined as presented in table 2. According to the Ministry of Roads and Highways (MRH) specifications of Ghana (Ministry of Transportation, 2007), and the grading analysis, the soil falls into a G30 grading envelope which is essentially useful as subbase material for roads.

Table 2: Grading Characteristics of the Control Sample

Grading Characteristic	Value
D_{10} (mm)	0.001
D_{30} (mm)	0.02
D_{60} (mm)	2.1
Cu	2100
Cc	0.19
% passing 75 µm	48.6
% passing 0.425 mm	56.0
% passing 2.0 mm	59.2
% passing 4.75 mm	66.5
Effective Size (mm)	0.001

Classification According to USCS

According to the USCS (ASTM, 1988), and from the grading characteristics and consistency limits above, the soil is classified as clayey gravel with sand or gravel-sand-clay mixtures with the group symbol GC because the PI plots above the A-line.

Classification According to AASHTO Classification System

According to the AASHTO Classification System (AASHTO M145-91, 2012), and from the grading characteristics and consistency limits indicated above, the soil is classified as Silt-Clay material with the group symbol A-6(5).

Liquid Limit, Plastic Limit and Plasticity Index of the Test Specimens

The results of liquid and plastic limit tests conducted on the sample with the various soaking durations of the extract gave the following results presented in table 3.

Table 3: Consistency Limit Results of LBPE Stabilized Material

LBPE STABILIZED MATERIAL RESULTS			
Duration of Soaking	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
1 Day	39.57	23.02	16.55
2 Days	39.57	25.00	14.57
3 Days	39.76	25.81	13.95
4 Days	40.95	25.27	15.68
5 Days	39.87	23.94	15.93
7 Days	40.19	23.26	16.93
14 Days	40.08	22.64	17.44
21 Days	34.28	21.97	12.31

28 Days	40.87	24.31	16.56

It can be seen that the liquid limit values obtained from the test specimens when using only the extract to conduct the liquid limit test gave higher results than that of the control. The highest liquid limit value of 40.95 was recorded for 4-days soaking duration. This is followed by the 28-days soaking duration with a value of 40.87. The lowest liquid limit value of 34.28 was recorded for the 21-days soaking duration and this happens to be the only liquid limit value of the test specimens lower than that of the control. Consequently, comparing the Liquid limit results of the test specimens with that of the control value of 38.25, shows that the LBPE generally increases the Liquid limit value of the soil. The soils stabilized with LBPE were found to generally exhibit 3.5% – 7.1% higher Liquid Limit (LL) than the control. The increase in liquid limit of the soil on application of LBPE is expected and aligns with the works of Du *et al*., (2022), Du *et al*., (2021) and Nugent *et al*., (2009) who found out that liquid limit of kaolinite clay increases with biopolymer concentration.

Also, the plastic limit values obtained for the test specimen using only the extract for the plastic limit determination generally give higher results than that of the control. The highest value of 25.81 was recorded for the 3-days duration of soaking. This was followed by 25.00 for 2-days duration of soaking. The soils stabilized with LBPE were found to generally exhibit 0.9% – 15.0% higher Plastic Limit (PL) than the control. The 21-days duration of soaking however, recorded the lowest value of 21.97 which also happens to be the only plastic limit of LBPE stabilized soil which is lower than that of the control of 22.44.

Consequently, the plasticity index of all the LBPE specimens except those of the 2-days, 3-days, 4-days and 21-days soaking durations were higher than that of the control. The least plasticity index of 12.31 was recorded for the 21-days soaking duration. The PI for the 3-days and 2-days soaking duration which were found to be 13.95 and 14.57 respectively as compared to the control value of 15.81. Compared with the control, the Plasticity Index (PI) values were lower by up to 22.1%. Lower PI is desirable in road construction materials.

Overall, the optimum soaking duration to obtain best improvements in the soil properties (consistency limits) is the 3-days soaking duration. This deviates a little from the recommended 24 hours soaking duration according to Aguwa *et al*. (2016) for optimum extraction. The difference could be attributed to the properties investigated in these studies as well as pounding of the husks in this study as compared to the cutting of the pods into smaller pieces which was employed in their study. These analyses are illustrated in figures 4 to 6.

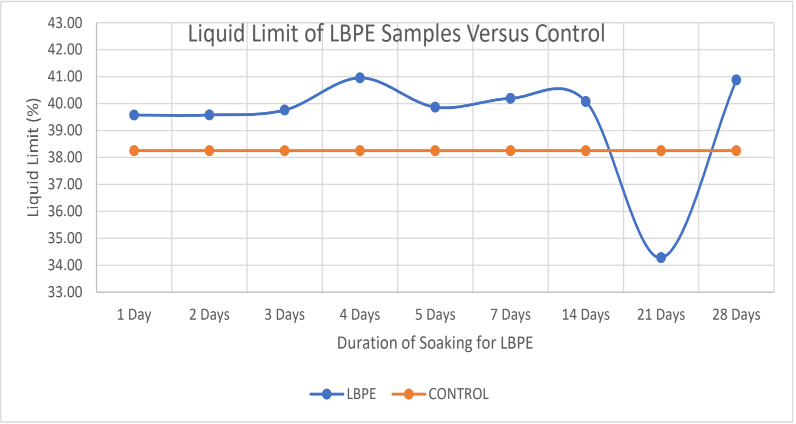

Figure 4: Liquid Limit values of LBPE stabilized soil versus Control

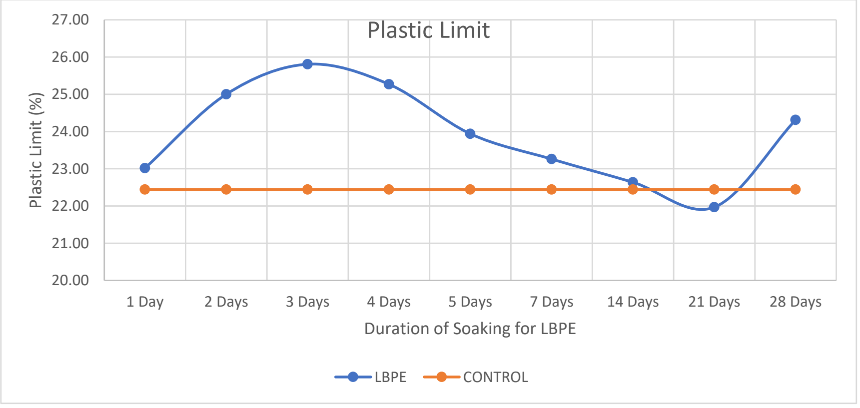

Figure 5: Plastic Limit Values of LBPE Stabilized Soil Versus Control

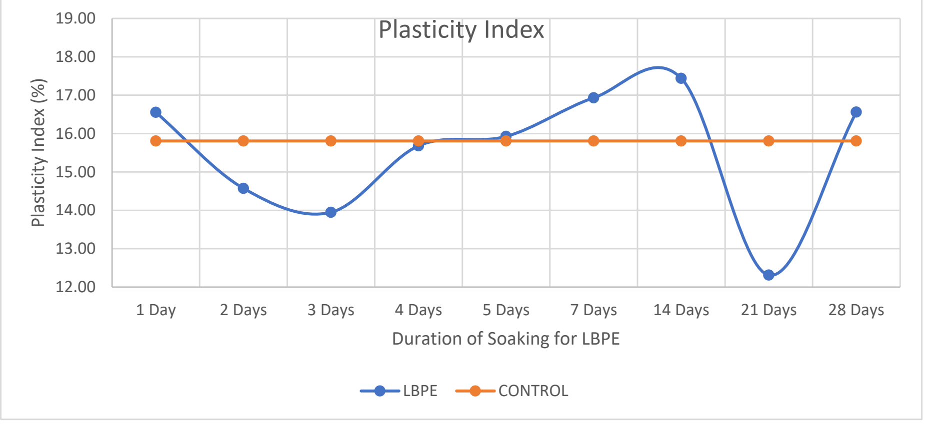

Figure 6: Plasticity Index Values of LBPE Stabilized Soil Versus Control

Consistency Index and Liquidity Index

Consistency index is a measure of the shear strength of the soils (Madenford and Scholtes, 1973; Mathur *et al*., 2017; de Oliveira *et al*., 2019). From literature, the higher the consistency index, the higher the unconfined compressive strength of the soil is expected to be (Zidan, 2020; Wang *et al*., 2022). The consistency index was evaluated and the 3-days soaking duration performs better with a value of 1.90 followed by those of 2-days, 4-days and 21-days with CI values of 1.8,1.76 and 1.70 respectively. The lowest consistency index value of 1.53 was evaluated for the 14-days soaking duration which is also the only CI value lower than that of the control. The consistency index for the control soil was determined to be 1.58. Improvements of up to 20.2% in the Consistency Index of the LBPE samples over the control were observed.

Liquidity index is also related to the consistency index and therefore also relates to the relative strength of the soil (Wroth and Wood, 1978; Vardanega and Haigh, 2014; Mathur *et al*., 2017; Senoon and Hussein, 2018). Considering the liquidity index, the lowest value of -0.90 was evaluated for the 3-days soaking duration. This was followed by 2-days, 4-days and 21-days soaking durations which recorded -0.80, -0.76 and -0.70 respectively as values for the liquidity index. The highest liquidity value of -0.53 was again assessed for the 14-days soaking duration, a value which is higher than that of the control which was estimated to be -0.58. It can be seen that the algebraic sum of the consistency index and the liquidity index is always a positive one. Improvements of up to 55.1% in the liquidity index of the LBPE samples over the control were observed.

Figures 7 and 8 depict these results. The improvements in the consistency index and the liquidity index of the soil stabilized with LBPE is an indication that LBPE could improve the strength of lateritic soils.

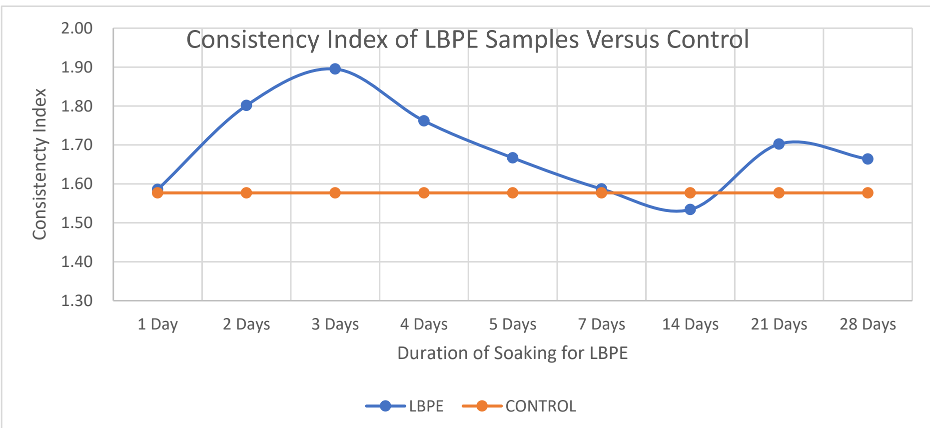

Figure 7: Consistency Index Values of LBPE Stabilized Soil Versus Control

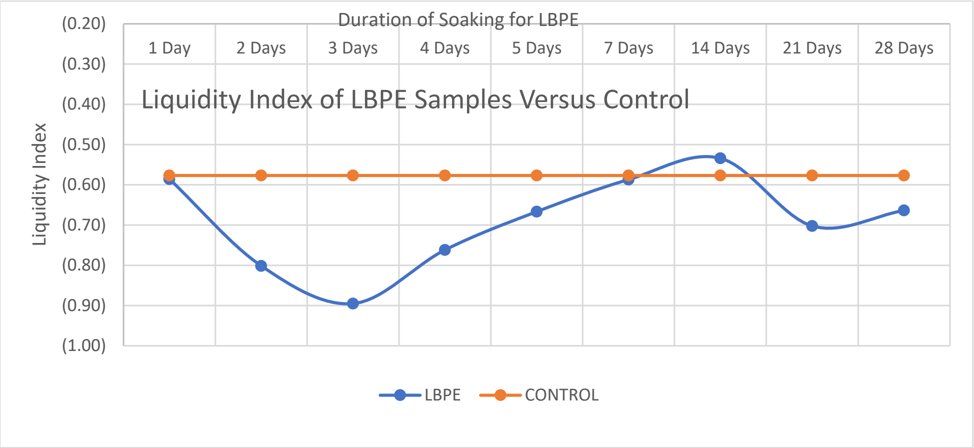

Figure 8: Liquidity Index Values of LBPE Stabilized Soil Versus Control

CONCLUSIONS AND RECOMMENDATIONS

Differences in the Atterberg limits of the soil treated with LBPE were observed as compared to the soil that was not treated with LBPE. Increases in both liquid limit and plastic limit were recorded for soils stabilized with LBPE as compared with soils not treated with LBPE. Consequently, the plasticity index of soils treated with LBPE shows mixed results. The 2-days, 3-days, 4-days and 21-days soaking durations of LBPE show lower plasticity index values compared to the control. This is a desirable property in terms of road construction as most soils suitable for road pavement construction have lower plasticity index values (AASHTO M145-91, 2012).

Again, the consistency index which gives an indication of the firmness (strength) of the soil improved for soils stabilized with LBPE while the liquidity index values exhibited lower values. This also conforms to the literature since soils with lower liquidity index are better than soils with higher liquidity index (Vardanega and Haigh, 2014; Mathur *et al*., 2017; Zidan, 2020; Wang *et al*., 2022). Soils treated with LBPE have higher consistency indices as compared to the control and hence are expected to possess higher shear strength than the control.

The best improvements in the Atterberg limits of the soils treated with LBPE can be seen in the 2-day, 3-day, and 21-day soaking duration which are also evident in the improvement of the group index of the AASHTO classification for these stabilized soils.

With regards to the Liquidity index and consistency index, the best results are recorded for 3-day, 2-day, 4-day, and 21-day soaking duration.

Overall, the optimum soaking duration to obtain the best improvements in the soil properties is the 3-day soaking duration. LBPE obtained from 3-days soaking was able to improve the properties of the soil such that the classification of the stabilized soil changes from clayey gravel or gravel-sand-clay mixtures (GC) to silty gravel or gravel-sand-silt mixtures (GM). According to the AASHTO classification, the soil stabilized with LBPE obtained from a 3-day soaking duration was able to improve the group index from 5 to 4. Again, according to the Ghana Ministry of Roads and Highways (MRH) specifications for natural gravel base course and subbase course materials, the 3-day soaking duration has improved the material which initially met a G30 plasticity index requirement (16% maximum) to a G40 plasticity index requirement (14% maximum), which can be used as base course for sealed rural roads subject to its California bearing ratio (CBR) and other properties being within the acceptable range for these classes.

Thus, LBPE can be used to improve marginal soils to meet technical specifications in natural gravel road pavement layer construction and three days soaking duration gives optimum results. The current study is limited to the assessment of LBPE stabilization on the consistency limits of lateritic soils. Further works are currently ongoing to determine the strength characteristics through compaction, settlement as well as erosion and durability characteristics of lateritic soils stabilized with LBPE.

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Declaration of Conflict of Interest

The authors declare that there is no conflict of interest neither is there any known competing financial or personal interests that could influence this study.

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