Effect of Locust Bean Pod Ash on Strength Properties of Weak Soils

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Abstract

Chemical stabilization of weak subgrade soils using locust bean pod ash (LBPA) produced from incinerator burnt locust bean pod waste was studied and reported in this paper. The LBPA was considered as a Class C group of the ASTM (American Society for Testing and Materials) pozzolan. The soils used in the study were obtained from depth of exhausted good quality materials of old borrow pits along the Minna-Kataeregi-Bida road in north-central Nigeria. The materials were analyzed for main geotechnical index properties and compaction characteristics. The LBPA pozzolan stabilizer was administered to the raw soil up to 12% and at a rate of 2%. The LBPA-treated samples were cured under moist conditions for a period of seven days before strength tests were carried out. The experimental results comparing the strength of the natural soil samples with the LBPA-stabilized samples revealed that LBPA increases the California Bearing Ratio (CBR) and unconfined compressive strength of the weak AASHTO (American Association of State Highway and Transportation Officials) classified A-7-6 and A-6 subgrade soils. An optimum stabilizer content of 8% was determined with about 50% advantages in the CBR (increase in CBR of stabilized soil / CBR of raw soil × 100) for both soaked and unsoaked conditions. At the established optimum stabilizer content, the weak hitherto unsuitable soils have been improved to meet the requirements for Type 2 subbase road development soils.

***Keywords**: Locust bean pod ash (LBPA), California bearing ratio (CBR), unconfined compressive strength, stabilizing agent, pozzolan.*

1. Introduction

Locust bean pod husks are a waste byproduct of agricultural processing of the African locust bean fruit. Substantial quantities can be found across northern Nigeria during the harvest season. Across the globe, much 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 2011). The transportation, construction, and environmental industries have the greatest potential for reuse because they use large quantities of earthen materials annually (Basha *et al*. 2003).

Locust bean pod, which is a waste agricultural biomass (WAB) obtained from the fruit (Fig. 1) of the African locust bean tree (*Parkia Biglobosa*), is the material resource required for the production of locust bean pod ash (LBPA). The harvested fruits are ripped open while the yellowish pulp and seeds are removed from the pods. The empty pods are the needed raw material. The pods make up 39% of the weight of the fruits while the mealy yellowish pulp and seeds make up 61% (Adama and Jimoh 2011).

Fig. 1. Close up view of locust bean fruit.

The results of the particle size distribution and chemical analysis of LBPA confirm that it has pozzolanic properties and can be classified under the Class C group of pozzolans on the ASTM (American Society for Testing and Materials) classification system. As such, it can be recommended for use as a chemical stabilizing agent in weak soils for road construction (Adama and Jimoh 2011).

Hence, the primary objective of this study is the evaluation of LBPA as a chemical stabilizer that could be used as stabilizing agent in weak subgrade soils for road construction focusing on CBR and unconfined compressive strength properties.

The effect of LBPA on compaction characteristics of weak subgrade soils is investigated further by Adama *et al*. (2013) in a separate study.

2. Theory

2.1 Production of Ash from Waste Agricultural Biomass

Waste agricultural biomass (WAB), which includes rice husks saw dust, palm kernel shells, locust bean pod, etc., usually poses health risks to the environment where it is found in large quantities, because it pollutes the environment in diverse ways. As such, efforts should be made to find alternative ways and methods for recycling WAB and achieve environmental friendliness so that it can be of much beneficial use to mankind (Ogundipe and Jimoh 2009, 2012; Yusuf and Jimoh 2012).

For the determination of the most convenient and economical temperature required for conversion of WAB to ash, the losses on ignition (LoI) tests carried out revealed that the optimum burning time and temperature were 2 hours and 500^oC, respectively. The loss in weight represents the quantity of unburned carbon present in the material which is often a good indication of how it will affect the air content (Wan Ab Karim Ghani *et al*. 2008). Also, in the combustion process of rice husk ash, the organic constituents are not decomposed at temperatures below 450^oC (Tutsek and Bartha 1977).

Silica is usually the major chemical compound contained is most ash residues after the combustion process of WAB and this has health issues arising because all forms of crystalline silica represent a very serious health hazard (OSHA 2004). The forms that develop at high temperatures, i.e. crystobalite and tridymite are particularly harmful. Exposure to crystalline silica via inhalation can lead to a number of diseases, the most common being silicosis (OSHA 2012). Crystalline silica is classified as carcinogenic to humans, and the International Agency for Research on Cancer (IARC) concluded that there was sufficient evidence in humans for the carcinogenicity of crystalline silica (IARC 1997). Although amorphous ash in the form produced at lower temperatures less than $1,000^oC$ does not contain more harmful forms of silica, it can pose respiratory hazard, particularly if finely ground (ETSU 2003).

2.2 Chemical Composition of Locust Bean Pod Ash (LBPA)

The test results showing quantities of the respective chemical constituents of the LBPA sample are presented in Table 1 (Adama 2010).

Table 1. Chemical composition of LBPA (powdery).

Chemical composition	Percentage (%)
Na_2O	1.21
K_2O	5.62
MgO	2.01
Pb_2O_5	5.82
Fe_2O_3	11.51
Al_2O_3	13.05
CaO	15.71
SiO_2	39.01
Losses on ignition (LoI)	6.00

2.3 Materials

The locust bean pods used in this research were sourced from Doko town in Niger state of Nigeria. The material is usually available as a waste product of agricultural processing of the locust bean fruits during the harvest season. LBPA was produced by incineration attaining 500^oC, after which the ash was ground into fine powdery form. The weak subgrade soils were obtained from depths of 2 m and below, where good quality road soils, and have been exhaustively exploited at the old borrow pits at chainage (Ch.) 3+100, 6+950, 22+150, 33+200 and 43+100 locations along the Minna-Kataeregi-Bida road in Niger state, Nigeria.

2.4 Equipment

Facilities at a civil engineering laboratory of the Federal University of Technology, Minna, Niger state, Nigeria, were used for determining the engineering properties of the soils and also for compaction tests.

3. Test Results and Discussion

3.1 Analysis of Soil Samples

The results of particle size distribution of the soil samples are summarized in Table 2, while that of the consistency limits and the AASHTO classification are shown in Table 3, accordingly. The particle size distribution curves are displayed in Figs. 2-6, respectively, for samples at Ch. 3+100, Ch. 6+950, Ch. 22+150, Ch. 33+200 and Ch. 43+100.

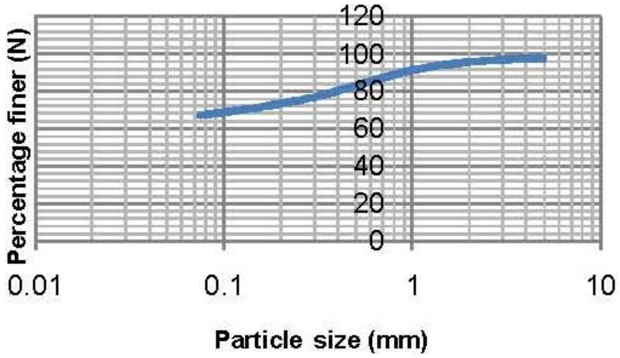

Fig. 2. Particle size distribution curve of soil sample from Ch. 3+100.

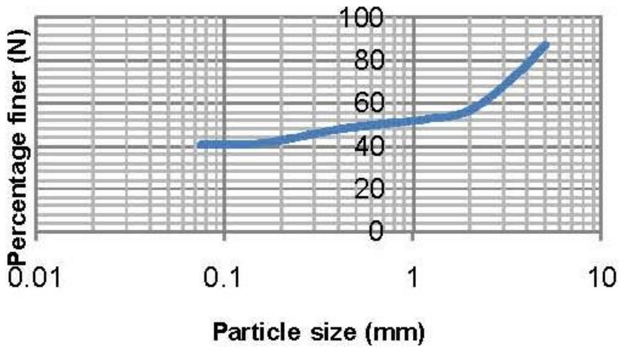

Fig. 3. Particle size distribution curve of soil sample from Ch. 6+950.

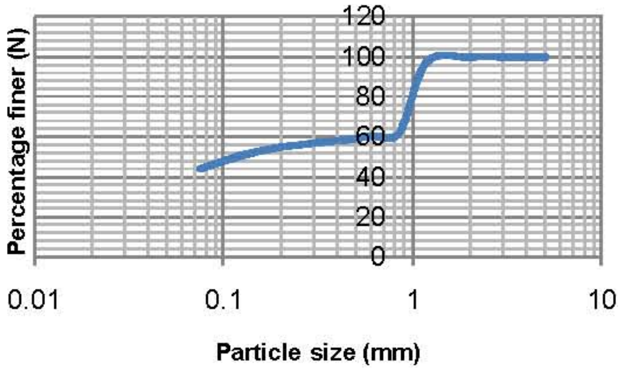

Fig. 4. Particle size distribution curve of soil sample from Ch. 22+150.

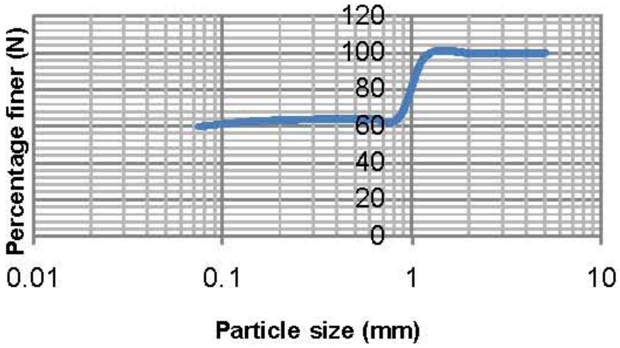

Fig. 5. Particle size distribution curve of soil sample from Ch. 33+200.

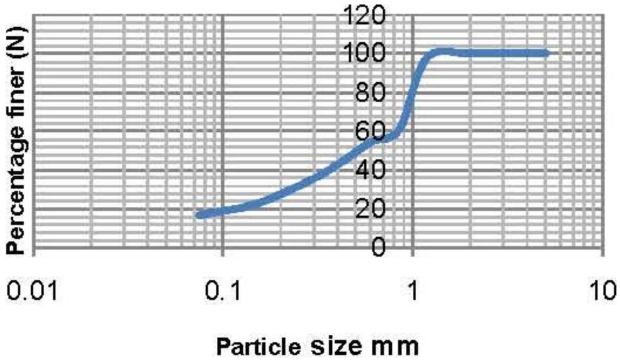

Fig. 6. Particle size distribution curve of soil sample from Ch. 43+100.

Table 2. Particle size distribution of samples, percentage (%) passing.

Particle size (mm)	Ch. 3+ 100	Ch. 6+ 950	Ch. 22+ 150	Ch. 33+ 200	Ch. 43+ 100
5	97.8	87.0	100	100	100
3.35	97.3	71.6	100	100	100
2.0	95.7	56.6	100	100	100
1.18	92.8	52.4	97.5	98.3	97.6
0.85	89.7	51.1	62.5	64.4	60.9
0.60	85.3	49.6	60.5	64.1	54.6
0.425	81.1	48.1	58.4	63.8	44.6
0.30	77.0	45.6	57.0	63.5	35.7
0.15	71.4	41.0	52.8	62.6	22.8
0.075	67.5	40.5	44.1	59.6	16.8

Table 3. The geotechnical index and classification properties of the studied soils.

S/No.	Location	Consistency limits		Particle size, % passing (mm)			*AASHTO Classification
		LL	PI	2.0 No.10	0.425 No.40 No.200	0.075	
1	Ch. 3+100	48	21	95.7	81.1	67.5	A-7-6(15)
2	Ch. 6+950	39	23	56.6	48.1	40.5	A-6(4)
3	Ch. 22+150	44	20	100	58.4	44.1	A-7-6(5)
4	Ch. 33+200	49	21	100	63.8	59.6	A-7-6(11)
5	Ch. 43+100	43	24	100	44.6	16.8	A-7-6(5)

*AASHTO classification chart, Tables 15.1 and 15.2 (Wright and Paquette 1987)

3.2 CBR and Unconfined Compression Strength

3.2.1 CBR test

CBR test was carried out on natural soil samples and on samples treated with the stabilizer, LBPA, at respective optimum moisture and AASHTO energy level according to BS 1377 (1990). Samples treated with LBPA were cured in a moist room for seven days before the compression tests were carried out. Only representative samples from three locations (2 of A-7-6 and 1 of A-6) were tested with varying LBPA contents to establish the optimum values desired for stabilization. The results are shown in Table 4 and Figs. 7 and 8.

Table 4. CBR - stabilizer content (LBPA pozzolan).

LBPA Content (%)	Ch. 6+950 (A-7-6)		Ch. 22+150 (A-6)		Ch. 33+200 (A-7-6)	
	Soaked (%)	Unsoaked (%)	Soaked (%)	Unsoaked (%)	Soaked (%)	Unsoaked (%)
0	18.0	22.0	11.0	19.0	11.0	21.0
2	20.0	24.0	14.0	21.0	12.0	24.0
4	23.0	29.0	18.0	25.0	14.0	27.0
8	27.0	35.0	22.0	27.0	17.0	29.0
12	24.0	25.7	15.0	21.0	13.0	23.5
Range of % increase on stabilization	11-50	8-46	28-100	10-42	9-54	12-34

*LBPA=Locust Bean Pod Ash

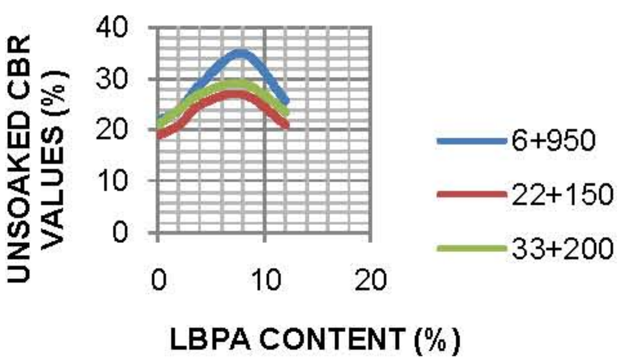

Fig. 7. Variation of CBR with LBPA content (unsoaked).

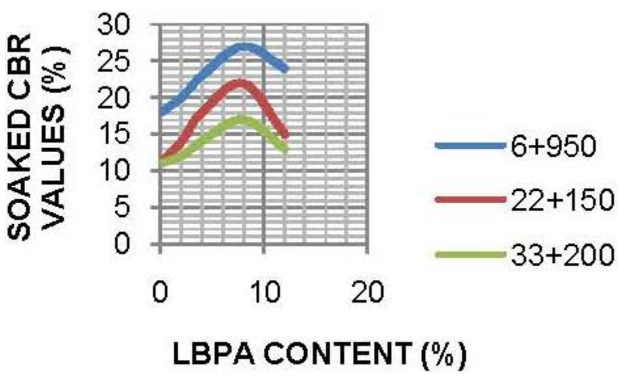

Fig. 8. Variation of CBR with LBPA content (soaked).

The results from Table 4, displayed in Figs. 7 and 8, revealed that varying LBPA content on samples from the three different locations resulted in optimum values of 8% for both soaked and un-soaked CBR, respectively. This indicates an improvement in soil strength because there is increase in CBR values of all stabilized samples as compared to the natural soil samples. The recorded increase in CBR values ranged from 2.5% to 12.5% reflecting percentage increase in the ranges 11-100 (soaked condition) and 8-46 (unsoaked). The implication of this result is that weak lateritic soils that are found from depths of 2 m and below on a site that falls short of the minimum requirement for subgrade, subbase or base course could be improved using the LBPA. Refer to the Nigerian General Specifications for Roads and Bridges, Federal Ministry of Works and Housing (1997), subgrade, subbase Type I, Type II and base CBR required values of 8-24, 30, 20 and 80%, respectively.

3.2.2 Unconfined compression strength

Results from unconfined compression tests for two locations are shown in Figs. 9 and 10, respectively. The tests were carried out on natural and LBPA-stabilized soil samples from both locations. As examples only, the detailed laboratory readings for the two sample locations are given in Tables 5 and 6.

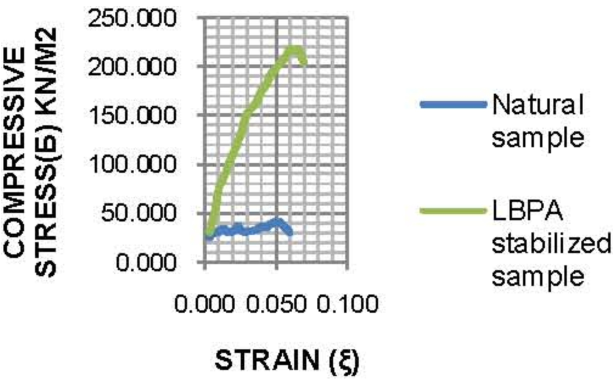

Fig. 9. Stress-strain graphs for sample at Ch. 3+100.

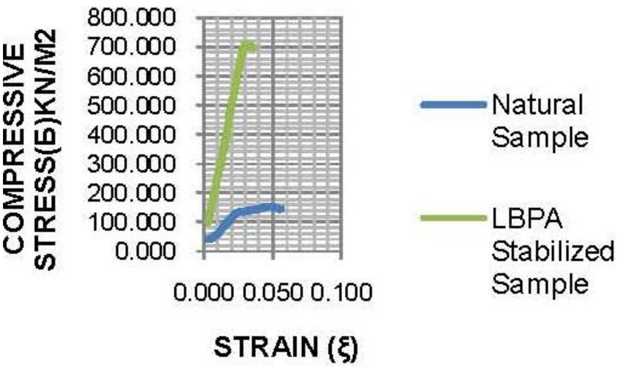

Fig. 10. Stress-strain graphs for sample at Ch. 6+950.

As shown in Fig. 9, the compressive stress at failure for soil at Ch. 3+100 has a much higher value for the soil stabilized with LBPA compared to the value for the raw (untreated) soil. The corresponding failure strains are 0.064 and 0.05.

Also, as it can be observed from Fig. 10, there is a definite failure stress at a strain of 0.030 for the stabilized soil. A much lower failure stress at a corresponding strain of 0.024 was recorded for the unstabilized soil at Ch. 6+950. The initial value of the modulus of elasticity increases substantially on stabilization with the LBPA. This implies higher resistance against load application. The soil sample stabilized with LBPA has a difference of 541.8 kN/m^2 in the unconfined compressive strength.

The results of the unconfined compression tests in Figs. 9 and 10 show an improvement in the unconfined compressive strength values of the LBPA-stabilized samples as compared to the natural soil samples after 24 hours of curing of the samples (soil LBPA admixtures). This result further buttresses the fact that LBPA has positive impact towards the improvement of weak lateritic soils for use as subgrade soils in road construction works in the tropics.

Table 5. Unconfined test data for sample from Ch. 3+100 (A-7-6).

S/N	Raw soil				LBPA Stabilized soil			
	Length change, ΔL	Load, P	$\varepsilon = \Delta L/L_o$	$\sigma = P/A_o(1-\varepsilon)$	Length change, ΔL	Load, P	$\varepsilon = \Delta L/L_o$	$\sigma = P/A_o(1-\varepsilon)$
1	25	0.029	0.003	25.724	25	0.036	0.003	31.371
2	50	0.035	0.007	30.624	50	0.057	0.007	50.027
3	75	0.036	0.010	31.787	75	0.086	0.010	75.416
4	100	0.039	0.013	34.166	100	0.100	0.013	86.968
5	125	0.036	0.016	30.957	125	0.114	0.016	99.061
6	150	0.037	0.020	32.087	150	0.129	0.020	111.071
7	175	0.043	0.023	36.899	175	0.143	0.023	122.998
8	200	0.037	0.026	31.872	200	0.160	0.026	137.294
9	225	0.037	0.030	31.764	225	0.179	0.030	152.712
10	250	0.039	0.036	33.369	250	0.193	0.036	163.811
11	275	0.043	0.039	36.278	275	0.207	0.039	175.344
12	300	0,043	0.043	36.154	300	0.214	0.043	180.770
13	325	0.046	0.046	39.032	325	0.228	0.046	192.158
14	350	0.049	0.049	41.291	350	0.236	0.049	197.480
15	375	0.049	0.053	41.148	375	0.244	0.053	203.953
16	400	0.043	0.056	35.657	400	0.250	0.056	207.999
17	425	0.037	0.059	30.795	425	0.263	0.059	217.934
18	450				450	0.263	0.063	217.172
19	475				475	0.264	0.066	217.586
20	500				500	0.250	0.069	205.100

Table 6. Unconfined test data for sample from Ch. 6+950 (A-6).

S/N	Raw soil				LBPA Stabilized soil			
	Length change, ΔL	Load, P	$\varepsilon = \Delta L/L_o$	$\sigma = P/A_o(1-\varepsilon)$	Length change, ΔL	Load, P	$\varepsilon = \Delta L/L_o$	$\sigma = P/A_o(1-\varepsilon)$
1	25	0.046	0.003	40.782	25	0.114	0.003	100.386
2	50	0.054	0.007	46.901	50	0.207	0.007	181.349
3	75	0.068	0.010	59.211	75	0.293	0.010	255.542
4	100	0.089	0.013	77.650	100	0.364	0.013	316.813
5	125	0.111	0.016	95.965	125	0.464	0.016	402.435
6	150	0.132	0.020	114.156	150	0.571	0.020	493.648
7	175	0.150	0.023	129.148	175	0.657	0.023	565.790
8	200	0.161	0.026	137.907	200	0.750	0.026	643.565
9	225	0.161	0.030	137.441	225	0.821	0.030	702.475
10	250	0.168	0.036	142.576	250	0.821	0.036	697.409
11	275	0.171	0.039	145.113	275	0.000	0.039	0.000
12	300	0,179	0.043	150.641	300	0.000	0.043	0.000
13	325	0.182	0.046	153.126	325		0.046	
14	350	0.186	0.049	155.590	350		0.049	
15	375	0.180	0.053	150.281	375		0.053	
16	400	0.175	0.056	145.599	400		0.056	
17	425	0.000	0.059	0.000	425		0.059	
18	450				450		0.063	
19	475				475		0.066	
20	500				500		0.069	

Note: Initial length is 76 cm, initial diameter is 38 cm, initial area A_o = 0.001134 m^2.

4. Conclusion

The following conclusions were made from the study. The Locust Bean Pod Ash (LBPA) is an effective pozzolanic stabilizer for road works. The CBR values obtained from the experimental results indicated increased strength mostly in the range of 8-54% within the 12% stabilizer content studied. An optimum stabilizer content of 8% was determined at which the advantage in CBR (increase in CBR of stabilized soil / CBR of unstabilized soil × 100) rose to 50-100%. The unconfined compression strength of the stabilization also showed increases ranging from 5.6 to 541.8 kN/m^2, thus indicating an improvement in the strength properties of the soils when stabilized with LBPA. Weak soils (AASHTO Class A-7-6 and A-6) experienced improved strength (soaked CBR > 20%) when stabilized with LBPA at the optimum content to meet the requirements of Type II subbase material. As such, it can be recommended for use as a chemical stabilizing agent of weak soils for road construction, especially in challenging situations of scarcity of good quality construction materials in urban road development.

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