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Strength Properties of Alkaline Activated Phosphoric Acid Stabilized Laterite

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Abstract: This study investigated the effect of alkaline activation on the properties of Phosphoric Acid (PA) stabilized laterite. Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of the laterite were determined to ascertain its suitability as a construction material. Laterite samples were stabilized with 1M and 2M PA at 5, 10 and 15%, respectively, by weight of dry soil. Some PA stabilized laterite were further mixed with an alkaline activator. All the stabilized laterites were moist cured for up to 14 days. The results show that the laterite was unsuitable as a road construction material in its natural state. The CBR of PA stabilized laterite improved with about 25%, while that with alkaline activation showed more improvement of up to 145%. The UCS of PA stabilized soil and that with alkaline activation increased with about 250% improvement. In conclusion, alkaline activation of phosphoric acid stabilized laterite soil for road construction has a great promise.

Keywords: California bearing ratio; unconfined compressive strength; yate's algorithm; statistical analysis; tropical laterite.

Introduction

Laterite and lateritic soils are used in tropical region to make bricks for building constructions and are also used as subbase materials in road construction. Laterite contains a considerable amount of clay-sized particles which tend to control its geotechnical properties [1–3]. This attribute usually neccessitate the stabilization of laterite before use. Stabilization of soils is simply the alteration of either or both of physical and chemical properties of soil to bring about improvement in their geotechnical properties. Alteration in chemical properties is brought about by the addition of various additives/chemicals [4–6]. Soil stabilisation involving the use of chemicals/ additives to alter the chemical properties of stabilized soil is refered to as chemical stabilization. The two traditional chemicals commonly used are cement and lime.

The use of cement comes with associated challenges including high cost and environmental hazards particularly the emmission of carbon dioxide which is a green house gas [7]. This has resulted in researches on partly subtituting or eliminating cement in soil stabilization.

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Additives and pozzolans including agricultural wastes such as rice husk ash [8–10], cassava peel ash [11-12], palm kernel shell ash [13–15] and saw dust ash [16–18] among others have been used. Industrial wastes such as cement kiln dust [19-20], ground granulated blast furnace slag [21-22] are also being used. In recent times the combination of alkali activators with the additives to form alkali activated binders reffered to as geopolymers has been on the increase [23–25]. Geopolymers are known as high-performance inorganic materials. The process of synthesising geopolymers by reacting amorphous alumino-silicate source materials (pozzolans) with an alkali (mostly sodium or potassium), and alkali earth metals such as calcium resulting in a three-dimensional, essentially amorphous, alumino-silicate gels capable of setting and hardening within a reasonable short period of time is reffered to as Alkaline activation [4-5]. Geopolymers have not only helped to reduce the environmental pollution caused by cement but results have shown a significant improvement in soils' mechanical properties and volume stability compared to cement [24].

The use of phosphoric acid for stabilization of fine-grained soils has become a subject of growing interest in recent years. This interest stems from the experimental observations that phosphoric acid exhibits impressive stabilizing ability in a wide variety of aluminosilicate soils and acid requirements for effective stabilization are low [26–31]. Acids are generally effective in removing alumina and other metallic oxides from clay minerals [29] and treatment using phosphoric acid which is a mineral acid has helped to improve strength and workability of laterite soil. Phosphoric acid is also non-toxic, readily available and has better economics of transport. These characteristics of phosphoric acid make it potentially competitive with conventional laterite soil stabilizers, such as portland cement, asphalt and lime.

Laterite is rich in iron and aluminium oxides, it is also acidic [32]. The iron and aluminium in laterite can combine with phopshate from phosphoric acid to form stable insoluble cementitious compounds in acidic soil environment [33]. It is also shown that the iron and aluminium phosphate compounds can be formed in highly alkaline environment. The successes of phosphoric acid, alkaline activation and the possibility of forming stable cementitious compounds in an alkaline soil environment spurred this research.

Various researches as previously mentioned have been carried out on the use of phosphoric acid to stabilize laterite and alkaline activation in improving soil geotechnical properties, however, not much study has been carried out on the treatment of soil using phosphoric acid with alkaline activation. The aim of this research is to determine the effect of alkaline activation on some geotechnical properties of phosphoric acid stabilized laterite soils.

Materials and Methods

The materials used for this study are laterite soil, phosphoric acid (H_3PO_4), sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). The laterite soil was obtained from a GPS location 7°29'53.2"N 4°26'57.6"E in Southwest Nigeria.

Index properties such as specific gravity, particle size analysis and Atterberg's limits (Liquid and plastic limits) were determined in accordance with ASTM D 854 [34], ASTM D 422 [35] and ASTM D 4318 [36], respectively . These index properties were determined to classify and ascertain the suitability of the laterite as a road construction material. Compaction properties (maximum dry density, MDD and optimum moisture content, OMC) of the laterite was determined using the standard proctor method with approximately 1 L mould, 2.5 kg rammer, 3 layers and 27 blows. The OMC was used to mix and reconstitute laterite which was compacted with a 2.5 kg rammer, at 3 layers with 54 blows into a 2 L mould. The change in number of blows and mould volume was made to achieve the same energy level as was used in the compaction test and because the larger mould is needed for California bearing ratio (CBR) test. The reconstituted and compacted laterite was used to determine the CBR and Unconfined compressive strength (UCS) in accordance with ASTM D1883-16 [37] and ASTM D2166 [38], respectively. In the case of UCS test, a number of 38 mm by 76 mm cylindrical samples were extruded from the compacted laterites and tested using the triaxial machine. The mineralogical compositions of the samples were analysed via X-ray diffraction (XRD) and representative XRD patterns obtained. The XRD was performed to obtain further evidence about the structure of the laterite.

Samples of the laterite soil were mixed separately with varying percentages (0, 5, 10 and 15%) of 1M and 2M phosphoric acid (PA) in order to determine the effect of only phosphoric acid on its CBR and UCS. Different PA stabilised laterites were then mixed with an alkaline activator. The alkaline activator used was 12M NaOH and Na_2SiO_3 mixed in ratio 1:2.5 (liquid-to-liquid ratio by mass) [15, 39-40]. The alkaline activator was mixed with the phosphoric acid in the ratio 1:2.5 following the work of Bakri [39]. The test program is presented in Table 1. L, LP and LPA in Table 1 refer to unstabilized laterite, Laterite stabilized with only PA and laterite stabilized with PA and alkaline activator, respectively. The first (i.e. 1 or 2) and second (i.e. 5, 10 or 15) numbers in Table 1 refer to the molarity and percentages of PA, respectively.

Table 1. Test Program for Laboratory Experiments

Test Symbol	Molarity of PA (M)	% of PA (Pe)	Curing age (days) (C)	Remark
L	-	0	0	Control Test
LP1-5	1M	5	0,7,14	
LP1-10		10	0,7,14	
LP1-15		15	0,7,14	No Alkaline
LP2-5	2M	5	0,7,14	Activation
LP2-10		10	0,7,14	
LP2-15		15	0,7,14	
LPA1-5	1M	5	0,7,14	
LPA1-10		10	0,7,14	
LPA1-15		15	0,7,14	With Alkaline
LPA2-5	2M	5	0,7,14	Activation
LPA2-10		10	0,7,14	
LPA2-15		15	0,7,14	

The stabilized laterites were cured in a sealed paper bags at room temperature for 0, 7 and 14 days. The CBR and UCS of the stabilized laterites were determined on these days. The results were analysed using analysis of variance (ANOVA) to evaluate the effect of molarity of acid used (M), percentages of PA (Pe) and curing days (C) on CBR and UCS of the stabilized laterites. A 2^4 factorial experiment was also performed to determine the coupled effect of the different factors i.e. alkaline activation (A), M, Pe and C on the CBR and UCS of the stabilized laterite. Design Expert 13 Trial

Version from Stat-Ease Inc., Minneapolis, USA, was also employed to develop the correlation. Linear model was selected to corelate factors.

Results and Discussion

Some Geotechnical Properties of Unstabilized Laterite

The summary of the geotechnical properties of the laterite in its natural state is presented in Table 2. The specific gravity obtained falls within the range of 2.55 and 4.6 which according to Gidigasu [3] indicates particles of a laterite soil. The high value of specific gravity obtained (> 3.00) shows the soil is rich in iron oxides and titaniferous minerals. The percentage (>50%) passing sieve no. 200 (0.075 mm sieve opening) indicates that the laterite is a silt-clay material according to American Association of State Highway and Transport Officials (AASHTO) [41] and a fine-grained soil according to Unified Soil Classification System (USCS) [42] classifications. These results show that the laterite can be stabilized with phosphoric acid since phosphoric acid is effective for the stabilisation of fine grained soils according to Michaels et al. [31]. The liquid limit (LL) of the soil (which is greater than 50%) shows that it is a high plasticity soil according to Das [43]. Using the particle size distribution and Atterberg's limits results, the laterite is classified as A-7-5 (10) according to AASHTO [41] indicating a fair to poor general subgrade rating and high plasticity silt (MH) according to USCS [42] indicating inorganic silt of high plasticity. These results imply that the soil requires stabilization before it can be suitable as a construction material.

The XRD pattern of the laterite is presented in Figure 1. The pattern shows an abundance of illite (39.6%), kaolinite (20.34%) and quartz (14.9%) which predominate laterite soils as observed from the works of [44–46]. The sample obtained shows a higher composition of illite to kaolinite and according to Gidigasu [3], laterite soils containing a high percentage of montmorillonite and illite may have lower strengths, a high pore pressure, a high swelling potential and other undesirable properties. The CBR value (< 30%) suggests that the soil may not withstand ground vibrations when vehicular load is applied and could be susceptible to erosion [47], hence requiring stabilisation. The Nigerian ministry of works and housing [48] specified a soaked CBR of greater than 30% for soil to be used as sub-base material and greater than 80% for road base material. Since the CBR is expected to reduce upon soaking [49], the laterite is thus not suitable as either sub-base or road base material in its natural state, hence the need for stabilization.

Table 2. Geotechnical Properties of the laterite in its natural state.

Property	Value
Natural moisture content (%)	16.43
Specific Gravity, G_s	3.14
% passing 4.75 mm	100
% passing 0.425 mm	82
% passing 0.075 mm	51
Liquid Limit, LL (%)	65
Plastic Limit, PL (%)	42
Plastic Index PI, (%)	23
Maximum Dry Density, MDD (g/cm^3)	1.39
Optimum Moisture Content, OMC (%)	21.6
California Bearing Ratio, CBR (%)	21.59
Unconfined Compressive Strength, UCS (kPa)	111.01

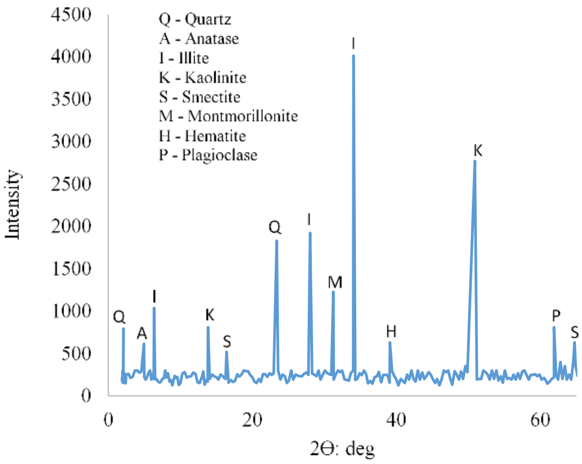
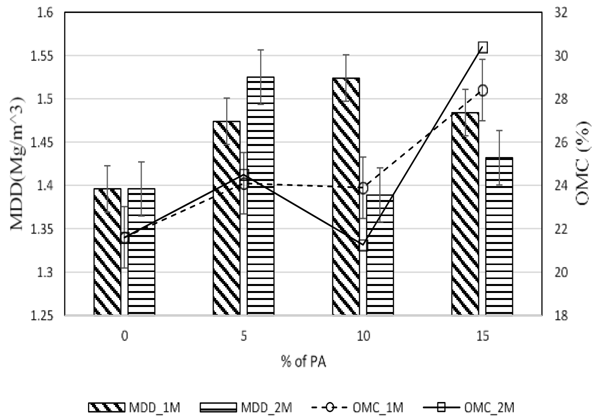


Figure 1. XRD Diffractogram of Laterite

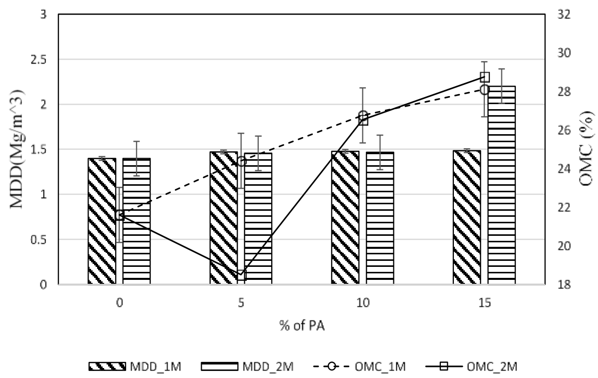
Effect of Phosphoric Acid on the Compaction Properties of the Laterite Soil

The compaction properties of the stabilized laterite are presented in Figures 2 and 3. Figure 2 presents the effect of molarity and percentage of PA while Figure 3 presents the effect of curing days and the percentage of PA on the compaction properties. The results show a general increase in the maximum dry density (MDD) and optimum moisture content (OMC) of the stabilized laterites with increasing PA content, although the increment was not uniform.

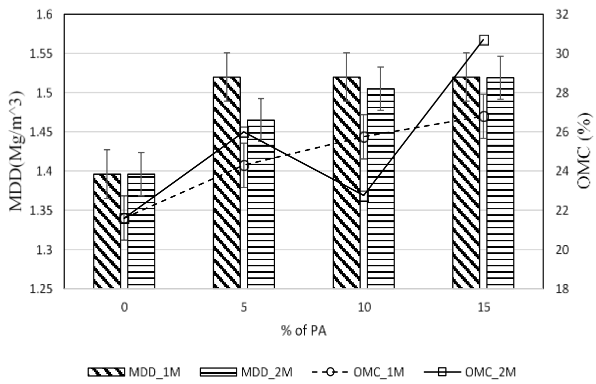
The MDD generally increased with increasing PA content especially for laterite stabilized with 1M PA (i.e. LP1 test) at all curing ages. The increment was more pronounced for both tests LPI and LP2 at 14 days of curing. This increment is consistent with that reported in [30], [31], [50] which stated that when fine grained soils are stabilized with phosphoric acid, higher values of MDD are usually obtained. The relatively low increment in MDD obtained for 2M stabilized laterite may be attributed to an increased rate at which lumps were formed leading to increased voids and thus relatively lower MDD.



(2a) 0 day curing day



(2b) 7 days curing

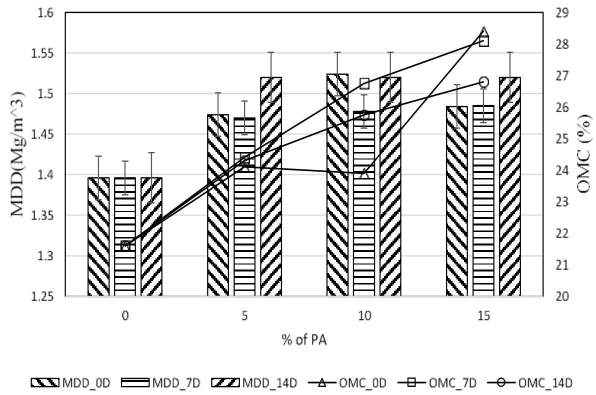


(2c) 14 days curing

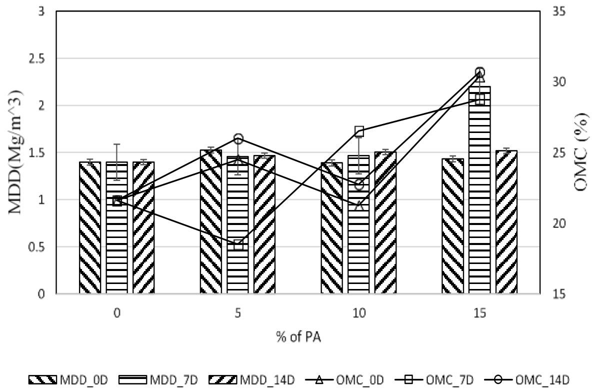
Figure 2. Compaction Properties of Stabilized Laterite at Different Curing Days

There was increment in the OMC of all the stabilized laterites except for some results for tests LP2. The decrease in moisture were not necessarily associated with increased MDD. This implies that the increase in MDD of the stabilized laterite must be as a result of chemical improvement within the stabilized laterite. These results also suggest that soil particles which were initially loose got bonded together due to the reactions between the free phosphate ions and alumina/iron present in the soil to form aluminate/ ferrous phosphate hydrate compounds [29] that bonded the soil particles together thereby reducing the voids in the soil and making the moisture added serve majorly as lubricant for the soil.

Statistical analysis of the results show that the percentage of PA used is a significant factor affecting both the OMC ($p = 0.000747$) and MDD ($p = 0.000576$) of 1M stabilized laterite while the effect of curing age is only significant on the MDD ($p = 0.08701$). The effect of the percentage of PA used was only significant on the OMC of 2M PA stabilized laterite while the curing age was not a significant factor affecting any of MDD and OMC.



(3a): 1M stabilized laterite



(3b): 2M stabilized laterite

Figure 3. Effect of Varying Percentages of PA and Curing Ages on the Compaction Properties of Stabilized Laterite

California Bearing Ratio (CBR) of Stabilized Laterite

The CBR of phosphoric acid stabilized laterite (i.e. LP1 and LP2 tests) at different curing ages is presented in Figure 4. The results show improved CBR values for some stabilized laterite while some results show decreased CBR values when compared to the CBR of the unstabilized soil. According to Bowles [51], the laterite can be rated fair subbase materials based on the CBR values. The results further show that only LP2-5 test at 7 days curing met the requirement of 30% CBR for a subbase soil according to Federal Ministry of Works and Housing [48].

The addition of alkali activator (AA) to PA stabilized laterite led to increased CBR as presented in Figure 5.

Comparing the CBR values presented in Figures 4 and 5, it can be seen that laterites stabilized with both PA and AA (Figure 5) have higher CBR values than those stabilized with only phosphoric acid (Figure 4). Most of the CBR data points also plots above the 30% standard specified by Federal Ministry of Works and Housing [48] for subbase material. The soil stabilized with 15% 1M PA at 7 days curing also plot above 50% CBR value, this rates the soil as a good base material according to Bowles [51]. The rate of reduction in CBR values for laterite stabilized with both PA and AA was also slower when compared with that of laterite stabilized with only PA. Generally, alkaline activetion greatly improved the CBR of the laterite and overall the CBR ratings regardless of the point of failure and behaviour were within values good enough for sub-base use and higher than the control values of 21.59% obtained for the unstabilized laterite. The increase in the CBR of the PA laterite on alkaline activation can be attributed to the geopolymerization that utilizes the free iron and aluminium in the laterite. Similar results were obtained by various researchers such as Cristelo et al. [52] and Rios et al. [53] who had utilized alkaline activation in improving soil properties.

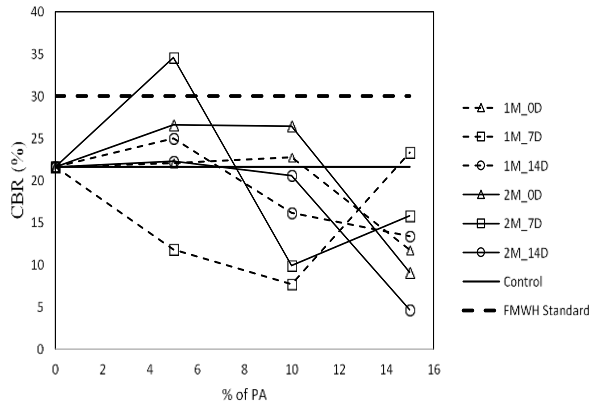


Figure 4. Effect of Phosphoric Acid on the CBR of Stabilized Laterite at Different Curing Ages

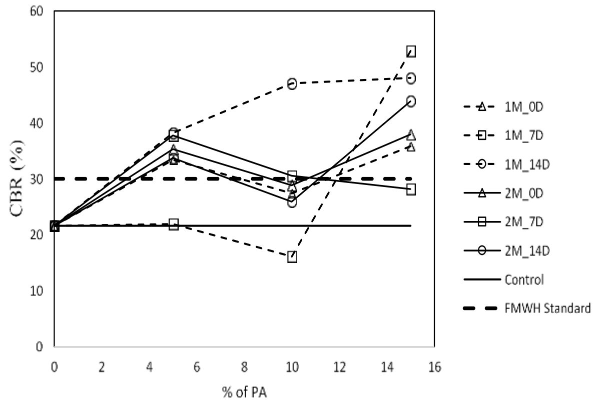


Figure 5. Effect of Phosphoric Acid on the CBR of Alkaline Activated PA Stabilized Laterite at Different Curing Ages

Statistical Analysis of CBR results

Statistical analysis using 2-way ANOVA shows that none of the factors considered are significantly affecting the CBR of LP tests. When the molarity was kept constant, the statistical significance of the percentage of acid (P) and the curing age (C) at 5% confidence level are presented in Table 3. Generally, P is a significant factor affecting the CBR of the stabilized laterite while the curing age is largely not significant as shown in Table 3. The p values for the selected factorial experiment models from Design Expert software are presented in Table 4. Table 4 gives a more robust representative values considering the coupled effect of the four factors considered than those presented in Table 3. The result show that the model is only significant at 6% confidence level. Only Alkaline activation is significant at 5% confident level.

Table 3. The P-value of Two-way ANOVA of the Influence of C and Pe on the CBR and UCS of Stabilized Soil

P-value (α = 0.05)	Factor	Testing program			
		LP1	LP2	LPA1	LPA2
P (CBR)	C	0.740	0.649	0.291	0.862
	Pe	0.652	0.203	0.094	0.026
P (UCS)	C	0.043	0.166	0.419	0.23
	Pe	0.013	0.047	0.039	0.00135

Table 4. Analysis of Variance for Selected Factorial Model for CBR

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1489.53	4	372.38	3.10	0.0615	not significant
A	1475.71	1	1475.71	12.30	0.0049	
M	11.80	1	11.80	0.0983	0.7597	
Pe	1.48	1	1.48	0.0123	0.9137	
C	0.5402	1	0.5402	0.0045	0.9477	
Residual	1320.19	11	120.02			
Cor Total	2809.72	15				

In order to have the coupled effect of all the factors on the CBR, Yate's algorithm using a 2^4 factorial experiment was conducted. The four factors considered in the experimental set up are alkaline activation (A), Molarity of the acid (M), percentage of acid used (P) and the curing age (C). The results obtained are presented in Table 4. The results show that A, P and C have positive effects on the CBR while M of acid has a negative effect on the CBR. Although, these effects are minimal especially for M, P and C as presented in Table 4. In quantitative terms, A has the highest effect on the CBR. When the interactions between factors are considered, the results show that only the interactions of A with P and A with C gave a positive effect. These results are presented in Table 5. The equation to evaluate CBR considering the interaction of the different factors is presented in Equation (1).

$$CBR = 28.45 + 9.60A - 0.86M + 0.30Pe + 0.18C \quad (1)$$

Table 5. Application of Yate's Algorithm for the California Bearing Ratio (CBR) of stabilized laterite

Run	A	M	Pe	C	CBR	Yate's Algorithm				Standardized Effect	Term	Sum of Squares	% Contribution
						1	2	3	4				
1	-	-	-	-	11.82	33.75	106.03	226.15	455.24	28.45			
2	+	-	-	-	21.93	72.28	120.12	229.09	153.66	19.21	A	1475.71	52.52
3	-	+	-	-	34.55	76.14	119.16	55.21	-13.74	-1.72	M	11.80	0.42
4	+	+	-	-	37.73	43.98	109.93	98.45	-21.24	-2.66	AM	1.48	0.052
5	-	-	+	-	23.3	63.18	13.29	6.37	4.86	0.61	Pe	0.5402	0.019
6	+	-	+	-	52.84	55.98	41.92	-20.11	77.84	9.73	APe	28.20	1.00
7	-	+	+	-	15.8	61.42	24.62	-24.09	-76.4	-9.55	MPe	378.69	13.48
8	+	+	+	-	28.18	48.51	73.83	2.85	-3.9	-0.49	AMPe	116.86	4.16
9	-	-	-	+	25	10.11	38.53	14.09	2.94	0.37	C	364.81	12.98
10	+	-	-	+	38.18	3.18	-32.16	-9.23	43.24	5.41	AC	43.82	1.56
11	-	+	-	+	22.27	29.54	-7.2	28.63	-26.48	-3.31	MC	33.99	1.21
12	+	+	-	+	33.71	12.38	-12.91	49.21	26.94	3.37	AMC	0.9506	0.034
13	-	-	+	+	13.4	13.18	-6.93	-70.69	-23.32	-2.92	PeC	45.36	1.61
14	+	-	+	+	48.02	11.44	-17.16	-5.71	20.58	2.57	APeC	26.47	0.942
15	-	+	+	+	4.65	34.62	-1.74	-10.23	64.98	8.12	MPeC	263.90	9.39
16	+	+	+	+	43.86	39.21	4.59	6.33	16.56	2.07	AMPeC	17.14	0.610
Lenth's ME												10.74	
Lenth's SME												21.80	

The percentage contribution of each of the factors to the model are also presented in Table 5. The main contributor to the model is A followed by C and MPe (both having almost equal contributions).

Unconfined Compressive Strength (UCS) of the Stabilized Laterite

The addition of phosphoric acid (PA) led to a general increase in the unconfined compressive strength (UCS) of the stabilized laterite as presented in Figure 6. All the data points plot above the control value (i.e. the UCS for unstabilized laterite), except for when P = 15% at 0 curing days for both LP1 and LP2 tests. The increase was as high as 251% in LP1-5 test at 14 curing days and 310% in LP2-10 test at 7 curing days. This improvement in UCS can be attributed to the reaction between the free phosphate ions and the released alumina and iron in the laterite. This reaction probably led to the formation of aluminium/iron hydrated phosphate compounds that bonded the laterite particles together [29, 54 - 55]. There was, however, different patterns for LP1 and LP2 tests. The optimum P was 5% and 10% at all the curing ages for LP1 and LP2 tests, respectively. These results show that the molarity of the acid used has varying effect on the UCS of the stabilized laterites. There was a general decrease in UCS with increase molarity.

Figure 7 shows the result of alkaline activation on the UCS of phosphoric acid stabilized laterites in LPA tests. There was improvement ranging from 15 to 150% in the UCS of the stabilized laterite, although, the improvement was not as much as recorded for LP tests. The result show that LP tests gave better result than LPA tests. More results also plotted below the control especially in LPA-2 tests. The increase in molarity also led to reduced UCS as in the case of LP tests. Similar results of reduced engineering properties of laterite with increased molarity of PA was recorded by Ayodele et al. [26]. The explanation was reduced workability of laterite mixed with higher molarity.

However, unlike in LP tests, LPA tests exhibited two kinds of behaviours with curing age. For LPA1-10, LPA2-5 and LPA2-15 tests, the UCS increased with curing age however, for LPA1-5, LPA1-15 and LPA2-10, there was an initial increase in UCS from 0 to 7 curing days before a decrease at 14 curing days.

Statistical Analysis of Unconfined Compressive Results

The P values obtained from Two-Way ANOVA of the results for UCS is as presented in Table 3. The result shows that the percentage of acid (Pe) used is a significant factor (at 5% confidence level) affecting the UCS for all the tests i.e. with or without alkaline activation. The effect of curing days was only significant for LP1 test. The p values for the selected factorial models from Design Expert software are presented in Table 6. The results further show that both A and M are significant factors at 5% confidence level affecting the UCS of the treated laterite.

The Yate's algorithm that shows the coupled effect of all the factors is presented in Table 7. The result show that A, M and Pe have negative effects on the UCS as seen and explained previously with only C having a positive effect on the UCS. A has the highest negative effect followed by M. Interactions of A with M, A with Pe, M with C and Pe with C, however, had positive effects on the UCS. Whereas, the interaction of M with Pe and A with C had negative effects on the UCS as presented in Table 5. The overall effect of the four factors was negative.

Equations 2 shows the model equation that relates the factors together for the UCS of the phosphoric acid stabilized laterite.

$$Y = 200.5 - 79.18A - 56.23M - 16.76Pe - 2.81C \qquad (2)$$

Table 7 which also contains the percentage contributions of all the factors shows that A and M are the main contributor to the model.

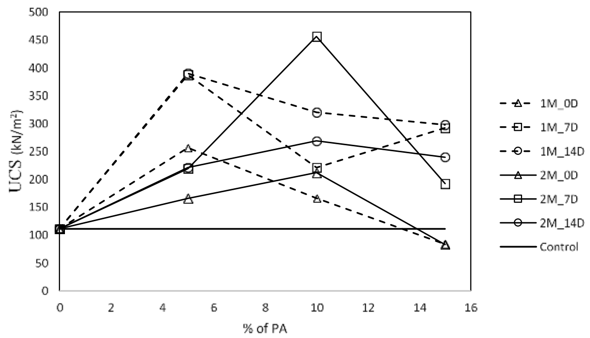


Figure 6. Effect of Phosphoric Acid on the UCS of Stabilized Laterite at Different Curing Ages

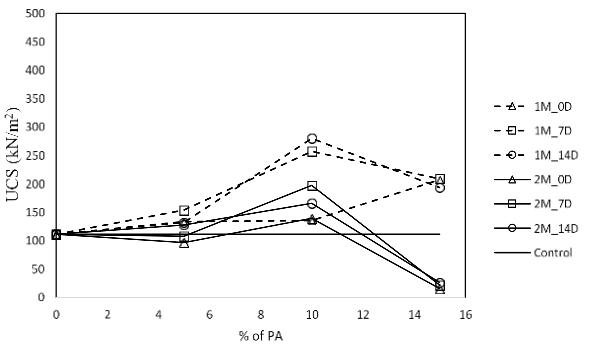


Figure 7. Effect of Phosphoric Acid on the UCS of Alkaline Activated PA Stabilized Laterite at Different Curing Ages

Table 6. Analysis of Variance for Selected Factorial Model for UCS

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.556E+05	4	38893.20	22.92	< 0.0001	significant
A	1.003E+05	1	1.003E+05	59.12	< 0.0001	
M	50638.50	1	50638.50	29.84	0.0002	
Pe	4493.02	1	4493.02	2.65	0.1320	
C	126.56	1	126.56	0.0746	0.7898	
Residual	18664.51	11	1696.77			
Cor Total	1.742E+05	15				

Conclusion

In this study, laboratory experiments were carried out to determine the effect of alkaline activation on the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of phosphoric acid stabilized laterite. From the results, the following conclusions can be made:

i. The maximum dry density of phosphoric acid stabilized laterite was improved even though there was corresponding increase in optimum moisture content. This shows a definite formation of cementitious compounds within the laterite as a result of the improvement.

ii. Both alkaline activation and only phosphoric acid improved the CBR of the treated laterite to up to 145% and 25%, respectively. Among the factors considered, alkaline activation has the most positive result on the CBR.

iii. There was up to 250% improvement in the UCS of the stabilized laterite, however, alkaline activation was not as effective as when only phosphoric acid was used.

iv. Statistical analysis using ANOVA and Yate's algorithm shows that curing age has the most significant effect on the UCS while alkaline activation has the most significant effect on the CBR.

Table 7. Application of Yate's Algorithm Analysis for the Unconfined Compressive Strength (UCS) of Stabilized Laterite

Run	A	M	P_e	C	UCS	Yate's Algorithm 1	2	3	4	Standardized effect	Term	Sum of squares	% Contribution
1	-	-	-	-	387.3	541.2	868.1	1581.5	3208	200.5			
2	+	-	-	-	153.8	326.9	713.4	1626.5	-1266.9	-158.34	A	1.003E+05	57.57
3	-	+	-	-	219.1	500.3	870	-598.34	-900.12	-112.5	M	50638.50	29.06
4	+	+	-	-	107.8	213.2	756.5	-668.56	90.22	11.3	AM	4493.02	2.58
5	-	-	+	-	291.7	521.7	-344.8	-501.36	-268.12	-33.5	Pe	126.56	0.073
6	+	-	+	-	208.6	348.3	-253.5	-398.76	124.98	15.62	APe	508.73	0.29
7	-	+	+	-	191.8	491	-351.2	34.92	-124.96	-15.62	MPe	976.25	0.56
8	+	+	+	-	21.4	265.5	-317.4	55.3	-483.5	-60.44	AMPe	308.18	0.18
9	-	-	-	+	389.8	-233.5	-214.2	-154.64	45	5.62	C	975.94	0.56
10	+	-	-	+	131.9	-111.3	-287.1	-113.48	-70.22	-8.78	AC	657.92	0.38
11	-	+	-	+	220.8	-83.1	-173.3	91.24	102.6	12.82	MC	105.88	0.06
12	+	+	-	+	127.5	-170.4	-225.4	33.74	20.38	2.55	AMC	14610.77	8.39
13	-	-	+	+	297.5	-257.9	122.2	-72.86	41.16	5.14	PeC	25.96	0.015
14	+	-	+	+	193.5	-93.2	-87.2	-52.1	-57.5	-7.19	APeC	206.64	0.119
15	-	+	+	+	239.5	-104	164.7	-209.42	20.76	2.60	MPeC	26.94	0.015
16	+	+	+	+	26.07	-213.4	-109.4	-274.08	-64.66	-8.08	AMPeC	261.31	0.150
Lenth's ME												32.51	
Lenth's SME												65.99	

v. Finally, the study has shown that alkaline activation of phosphoric acid stabilized laterite soil for road construction has a great promise.

Conflict of Interest

The authors wish to declare that there is no conflict of interest.

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