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Effect of PH on Geotechnical Properties of Laterite Soil Used in Highway Pavement Construction

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Abstract
Laterite is one of the major materials used in highway pavement construction in Nigeria. Its properties are affected by some environmental factors which may make it unsuitable for highway pavement construction. This research was aimed of investigating the effect of pH on geotechnical properties of Laterite soil used in highway construction.
Laterite soil sample was collected from a burrow pit at LAUTECH and it was sun dried for about 24 hours and then soaked in different pH solutions (pH =3.0, pH=5.0, pH = 7.0 and pH= 9.0) using diluted tetraoxosulphate (vi) acid (H_2SO_4) and ammonia. The container was perforated at the bottom in order simulate the actual field condition. The soil samples were taken from soaked sample at 14, 28, 42, 56, 70 and 84 days for sun drying and subsequent laboratory tests. The original and treated samples were subjected to the following laboratory tests: Sieve analysis, Liquid and Plastic limits, Plasticity index, British standard compaction and California bearing ratio.
The results showed that the pH of the solution has strong influence on the geotechnical characteristics of the Laterite soil when compared with the original soil sample. This influence caused reduction on the strength properties of the soil and thereby rending it unsuitable for highway construction.
Keywords: Laterite, pH, consistency limits, California bearing ratio,

1. Introduction

Laterite soil is one of the commonest materials that are widely used in the construction of Civil engineering infrastructures, such as earth dams, covers and liners, brick houses, roads and so on. Road pavement is constructed in layers in Nigeria; the layers are subgrade, subbase, base and surfacing. The first three layers are mostly constructed using Laterite soil depending on the expected traffic volume and intensity and suitability of the soil in terms of specifications (Agbede and Osuolale, 2003 and FMW, 1997). These first three layers are protected from infiltration of water by the surfacing which is mostly constructed using Asphaltic concrete, however, there are situations where all the layers are submerged by water. These may occur when an area is flooded with rain or river overflows its boundary. Various researches had been carried out on the geotechnical properties of Laterite soils (Agbede and Osuolale, 2003 and Okunade, 2010). However, fewer researches had been carried out in the new emerging interdisciplinary field of environmental geotechnics. Sunil, et al, 2006 investigated the effect of varied pH on geotechnical properties of Laterite at varying days. He discovered that the consistency limits increase with increase in number of days in the acidic condition but decrease with number of days in the alkaline condition. There was also reduction in the compressive strength with increase in number of days for both the acidic and alkaline conditions. However, their experimental set up can not be said to have perfectly simulated the actual field condition because the Laterite soil samples were only made into blocks before soaking in the acidic and alkaline solutions. The influence of Calcium and Copper salt on soil cohesion, angle of internal friction, consistency limits, compaction characteristics and California bearing ratio were investigated by Ayininuola et al, 2009 and Osuolale and Oluremi, 2010. The study revealed that calcium salt caused initial increase in the cohesion and angle of internal friction, although there was reduction in these properties after the initial increment. For the copper salt, there was a reduction in the consistency limits, which is a plus if the material will be used for Civil engineering construction, however, the strength of the soil reduces with increase in number of days. Sharma et al, 2010, Sharma et al, 2011 and Sharma et al, 2012 examined the effect of acid rain on the geotechnical properties of high and low plasticity and black cotton soils. It was revealed that the acid rain affects the consistency limits as well as the strength properties of the soil. The variation was more pronounced in soils with low plasticity than those with high plasticity. The various researches had examined the effects of various chemicals on the properties of soils but none had considered the soil been used for highway construction and most of them did not perfectly simulated the actual field condition. Therefore, this research is aimed at examining the effect of pH changes on the geotechnical properties of Laterite soil used in highway construction.

2. Mechanism of reaction

During acid rain, different types of dilute acid are produced depending on the type of gases in the atmosphere. In this research, sulphur (IV) oxide gas was considered. The gas can be a product of combustion of gasoline that contains some sulphur. The sulphur (IV) oxide reacts with further oxygen to produce SO_3 as shown in equation (1). The SO_3 is precipitated when there is rainfall and it reacts with the water to give dilute Hydrogen trioxosulphate (VI) acid as shown in equation (2).

$$2SO_{2((g)} + O_{2(g)} \rightarrow 2SO_{3(g)} \quad \text{--} \quad (1)$$

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)} \quad \text{--} \quad (2)$$

The Laterite soil contains some compounds but the oxides of silicon, aluminum and iron are the major constituents. The oxides react with the acid rain to give deposit of aluminum, silicon and iron salt as shown below in equations (3) to (5). The reactions between the oxides and the acid rain weaken the bond between the compounds of the Laterite soil thereby affecting the properties of the soil that had been used in construction of highways.

$$3H_2SO_{4(aq)} + Al_2O_3 \rightarrow Al_2(SO_4)_3 + 3H_2O \quad \text{----------------------} \quad (3)$$

$$2H_2SO_{4(aq)} + 2SiO_2 \rightarrow 2Si(SO_4) + 2H_2O + O_2 \quad \text{-----------} \quad (4)$$

$$2H_2SO_{4(aq)} + 2Fe_2O_3 \rightarrow 2Fe_2(SO_4) + 2H_2O + O_2 \quad \text{-----------} \quad (5)$$

3. Materials and Method

3.1 Materials

The core materials used in this research work are Laterite soil sample obtained from a burrow-pit located at Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria, Tetraoxosulphate (VI) acid (H_2SO_4), Ammonia and perforated plastic containers for simulating the field condition of infiltration of the acid rain into the highway pavement.

3.2 Method

300 Kg of Laterite soil sample was collected from the burrow-pit, the soil was thoroughly mixed in the laboratory in order to produce homogeneous sample. The homogeneous sample was divided into five portions. Each portion of the soil sample was stored in the big perforated plastic containers labelled I, II, III, IV and V. The containers were perforated at the bottom so that the water can drain slowly in order to simulate the actual field condition. The tetraoxosulphate (VI) acid and the Ammonia were used to prepare solution that has pH of 3, 5, 7 and 9. The container that was labelled I is the control set up while the solutions with pH of 3, 5, 7 and 9 were poured into containers labelled II, III, IV and V respectively. The five containers with its contents were then stored for about 90 days in the laboratory. Soil samples were collected from the containers at 14, 28, 42, 56, 70 and 84 days. The samples were air dried and laboratory tests were carried out on them in accordance with the procedures in BS 1377 (BSI, 1990). The laboratory tests are sieve analysis, liquid limit (LL) plastic limit (PL), plasticity index (PI), British compaction and California bearing ratio.

4. Results and Discussion

4.1 Properties of the original sample

The summary results of the engineering properties of the original soil before acidification are presented in Table 1. The sample is classified as A-2-6(0) using the AASHTO classification system. From the results, the sample contain less fine particles because the percentage passing sieve No. 200 is less than 35% and it implies that the material may not be vulnerable to swell when in contact with water. The consistency limits and California bearing ratio are with the specification of the Nigerian Ministry of works (FMW, 1997). Hence, the sample is a good subgrade material and it can be equally used as filling material.

4.2 Consistency limits after contamination

The results of the liquid and plastic limits and plasticity indices at various pHs are presented in Table 2 below. The liquid limits at pH of 3, 5 and 7 increased with increase in numbers of days, this may be due to ion exchange that took place between the H^+ and Al^{3+}, Si^{2+} and Fe^{2+} and deflocculation. In addition, the acid solution that was added to the soil might likely split up the particles of the soil thereby increasing the surface area and as a result makes the sample to absorb more water (Sunil et al, 2006). These results are in conformity with the finding of Sharma et al, 2011 and Sunil et al, 2006. It can also be deduced that the consistency limits decrease as the pH tends to neutral and later increase when the soil is in alkaline condition. This shows that the pH has serious effect on the consistency of soils, therefore, Highway engineers should make such that adequate drainages are provided all roads and possibility of acid rain infiltrating into the subsoil of highway pavement is eliminated.
The consistency limits however decrease with increase in numbers of days when the soil condition was alkaline in nature. There is a possibility of the ammonia reducing the surface area of the soil sample by increasing the bonding force between the particles.

4.3. Compaction

The results of the maximum dry density and the optimum moisture content are presented in Table 3 below. The MDD decreases with increase in number of days for each of the pH condition. This indicates that the compounds of soil particles are been disintegrated as shown in equations (3) to (6) in section 2. This reduction in density will definitely affect the strength of the soil sample. The OMC however increase with increase in number of days for each of the pH. These can be attributed to increase in specific surface area and texture as a result of the activities of the acid and the base.

4.4 *Strength characteristics*

The strength properties of all the samples were affected by the variation in pH with time. The CBR of the samples decrease with time but it is more significant in those samples that were soaked in water before carrying out the CBR test. It has been reported by Sunil, 2006 that the condition for laterization is availability of iron-rich minerals in the parent bed rock and the cementation in Laterite soil is due to the presence of free iron oxide. There is a possibility that the iron oxide had been leached by the acid and the base, thereby causing the bonding forces in between the soil particles to reduce and invariably causing the strength properties to reduce as it shown in Figure 1 below.

5. Conclusion

The study revealed that the geotechnical properties of Laterite soil are greatly affected by the change in pH. The consistency limits decrease with increase in number of days at the varied pH. The changes in pH causes cation exchange and this weakens the electric attraction force between the soil particles and invariably reduction in strength of Laterite soil.

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Table 1. Properties of the original soil before contamination

Property	**Value**
Percentage passing No. 200 BS sieve (%)	30.00
Liquid limit (%)	36.00
Plastic limit (%)	25.09
Plasticity index (%)	10.91
AASHTO classification	A-2-6(0)
OMC at British compaction (%)	12.50
MDD at British compaction (g/cm^3)	1.90
CBR (Unsoaked) (%)	37.86
CBR (Soaked) (%)	26.89

Table 2. Consistency limits at varied pH

	pH 3			pH 5			pH 7			pH 9		
Days	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)
14	38.00	25.00	13.00	40.00	18.89	21.11	37.00	15.43	21.57	45.00	21.34	23.66
28	41.00	19.15	21.85	42.00	30.73	11.27	36.00	21.81	14.19	44.00	19.26	24.74
42	45.00	16.93	28.07	43.00	34.93	8.07	54.00	15.41	38.59	44.00	24.22	19.78
56	45.00	26.76	18.24	43.00	21..96	21.04	40.00	17.12	22.88	41.00	14.36	26.64
70	48.00	23.84	24.17	47.00	21.40	25.60	44.00	26.00	18.00	40.00	19.31	20.69
84	53.00	22.86	30.14	49.00	21.12	28.88	41.00	20.79	20.21	36.00	18.25	17.75

Table 3. Compaction characteristics at varied pH

	pH 3		pH 5		pH 7		pH 9	
Days	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)	OMC (%)
14	1.93	15.00	2.00	11.00	1.90	12.50	1.93	14.00
28	1.88	11.75	1.95	15.50	2.03	13.00	1.93	16.00
42	1.85	13.50	1.92	17.00	1.85	13.00	1.85	12.50
56	1.86	13.00	1.87	15.00	1.96	15.00	1.80	16.00
70	1.82	15.00	1.85	12.50	1.87	15.00	1.80	16.50
84	1.74	17.50	1.80	16.00	1.87	17.75	1.73	14.75

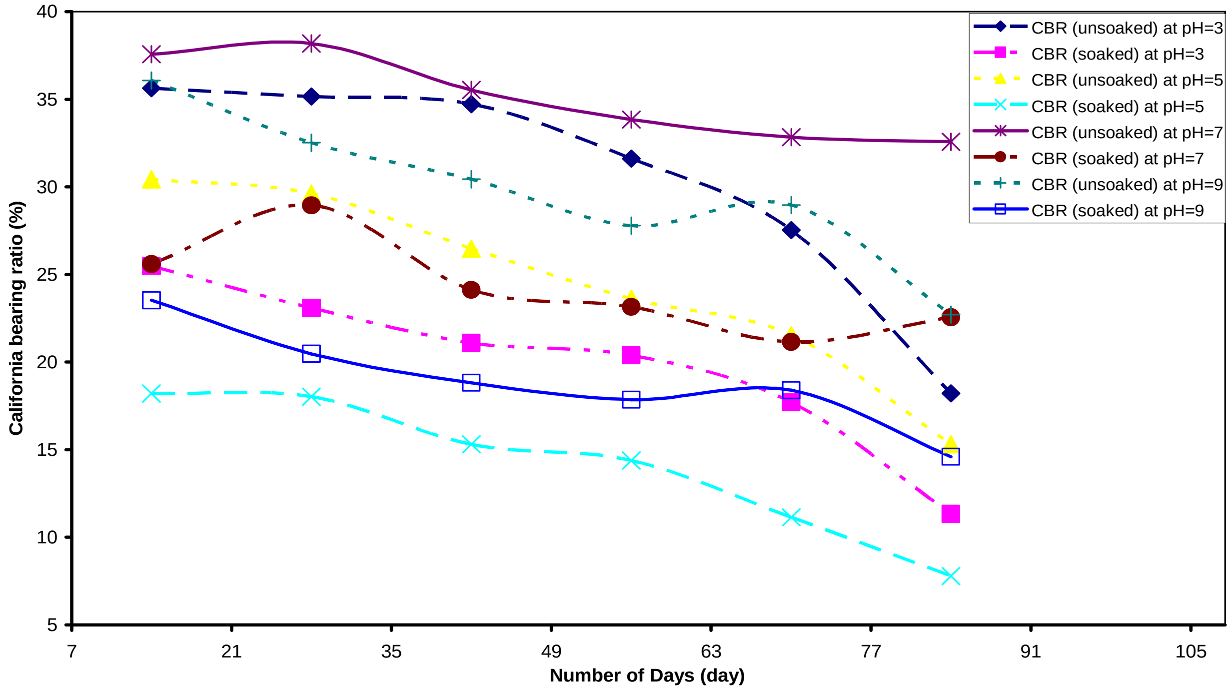

Figure 1. California bearing ratio at different pH