VOL. 1, NO. 1, OCTOBER 2012 ISSN 2305-493X
ARPN Journal of Earth Sciences

www.arpnjournals.com

# GEOCHEMISTRY OF SOIL STABILIZATION

Onyelowe Ken C.[1] and Okoafor F. O.[2]
[1]Department of Civil Engineering, College of Engineering and Engineering Technology, Umuahia, Nigeria
Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State, Nigeria
[2]Faculty of Engineering, University of Nigeria, Nsukka, Nigeria
E-Mail: konyelowe@yahoo.com

## ABSTRACT

This study was centered on elucidating the chemical reactions that bring about soil stabilization and modification during soil chemical stabilization without which there won't be the achievement of an anticipated improved soil for most engineering works. In the course of the study, this research has been able to establish the reactions between soil and cement, bitumen, and the chloride compounds. It has been established that the chemical compounds found in soil; quartz, feldspar, dolomite, calcite, montmorillonite, kaolinite etc. react with the chemical constituents found in different identified chemical stabilizers. Cement for instance contains the calcium silicates, the calcium aluminates, and the calcium alumino ferrites that in turn react with the soil (clay) chemical compounds to form the matrix of soil used as either subgrade or subbase materials. From the work, it is observed that quicklime reacts in a deeper extent by dehydrating the soil. Through this process of dehydration, it becomes more useful by changing to hydrated lime. This is the stage where the main chemical reactions that led to soil stabilization starts. This research work will better place designers, constructors and researcher on the choice of soil chemical stabilizer and techniques and the extent of chemical reactions that take place during soil chemical stabilization.

**Keywords:** geochemistry, soil stabilization, soil properties, lime stabilization, cement stabilization, bitumen stabilization.

## 1. INTRODUCTION

Data relating to soil properties are collected during the course of soil surveys. Soil properties are determined by field examination of the soils and by laboratory index testing of some bench mark soils. Established standard procedures are followed. During the survey, many borings are made and examined to identify and classify soils resulting from the soils' chemical and physical properties and to delineate them on the soil maps. Samples are taken from some typical profiles and tested in the laboratory to determine grain size distribution, plasticity, and compaction characteristics. The properties examined are at one time or another affected by the chemical properties and chemical constituents of the soil, (US Soil Survey, 2011).

### 1.1. Soil properties

### 1.1.1. Chemical properties of soil

Soil reaction is a measure of acidity or alkalinity and is expressed as a range in pH values. The range in pH of each major horizon is based on many field tests. For many soils, values have been verified by laboratory analyses. Soil reaction is very important in selecting admixtures and modifiers or stabilizers in evaluating chemical soil stabilization and in determining the risk of corrosion. Risk of corrosion pertains to potential soil-induced electrochemical or chemical action that dissolves or weakens uncoated steel or concrete or binders, (US Soil Survey, 2011).

### 1.2. Soil chemical constituents (Lateritic Soil)

The present work is confined to the chemistry of lateritic soil on modification or stabilization. To achieve a modified soil or stabilized soil matrix or mass, the chemical constituents of the natural soil have to react favorably with the constituents of the stabilizers or the admixture. The common chemical constituents contained in lateritic soils are as follows,

a) Silica
b) Alumina
c) Ferrite
d) Quartz
e) Dolomite
f) Calcite
g) Feldspar
h) Montmorillonite
i) Polygorskite
j) Kaolinite, (Abood *et al.*, 2007) and (Subramania, 2011)

These components react with soil stabilizers, modifiers and admixtures as well as water to establish the expected results, (Subramania, 2011).

## 2. CHEMICAL REACTIONS IN SOIL

Soils contain clay minerals as a result of weathering and provide support for all engineering works both vertical and horizontal. Soils have this sorptive property because of electrical charges and chemical contents and large surface area of the clay minerals, (Smith and Smith, 1998). Because of their structure and chemical composition, the clay minerals bear a negative charge. The charge is pH independent. From the surfaces of the clay minerals (aluminiusilicates and hydrated oxides of iron and aluminium) and from acidic groups, protons dissociate, (Subramania, 2011). This dissociation of protons gives a negative charge which is pH dependent. Hydrous oxides of iron and aluminium present in clay become positively charged at low pH by adsorption of protons.

### 2.1. Sources of electrical charge on soil clays

(i) Permanent negative charge on 2:1 and 2:2 clay minerals due to isomorphous substitution is discussed above.

(ii) pH dependent charges

a) Negative charges at broken surfaces and edges of clay minerals.

$$\text{SiOH—AlOH—SiOH—AlOH} \underset{H^+}{\overset{OH^-}{\rightleftarrows}} \text{SiOH—AlO}^- \text{---SiOH-AlO}^- + H_2O \tag{1}$$

b) Negative and positive charges on hydrous oxides of iron and aluminium.

$$\text{FeOH} \underset{H^+}{\overset{OH^-}{\rightleftarrows}} \text{FeOH} + H_2O \tag{2}$$

$$\text{FeOH}_2 \underset{H^+}{\overset{OH^-}{\rightleftarrows}} \text{FeOH} + H_2O \tag{3}$$

Because the pH-dependent charge arises to the surfaces and edges of the clay minerals, it is greater the more disordered in the structure.

### 2.2. Exchangeable cations and cation exchange capacity

As discussed previously, the negative charge of clay minerals varies with pH. The capacity of the soils to hold exchangeable cations therefore also depends on the pH. There are many standard methods for the determination of cation exchange capacity (CEC) of the soil, though the scope of the study is not extended to cover it.

### 2.3. Acid-base ion exchange reaction in soils

Soils act as buffer and resists change in pH. The buffer capacity of the soil depends on its type. The oxidation of pyrite in soil causes formation of acid-sulphate soils called "cat clays", (Bureau of Reclamation, 1998).

$$FeS_2+3.5O_2+H_2O \rightleftarrows Fe^{++}+2H^-+2SO_4^{-\,-} \tag{4}$$

Acid soils can be improved by the addition of lime.

$$\text{Soil}\}\ (H^+)^2+CaCO_3 \rightleftarrows \text{Soil}\}\ Ca^{++}+CO_2+H_2O \tag{5}$$

The soil may turn alkaline in the presence of basic salts such as $Na_2CO_3$ drought prone where there is less rain fall. Alkaline soils can be improved by the addition of aluminium sulphate or ferric sulphate.

$$2Fe^{3+}+3SO_4^{2-}+6H_2O \rightarrow 2Fe\,(OH)_3 \downarrow 6H^++3SO_4^{2-} \tag{6}$$

Sulphur also can be used to acidity the alkaline soils, since it oxidized to sulphuric acid in the presence of soil pressure.

$$S+1.5O_2+H_2O \longrightarrow 2H^++SO_4^{2-} \tag{7}$$

## 3. SOIL STABILIZATION CHEMISTRY

### 3.1. Soil reaction with lime

The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements. Indeed the structural strength of lime-stabilized soils can be factored into pavement designs. Lime can be used to treat soils to varying degrees depending upon the objective. The least amount of treatment is used to dry and temporarily modify soils. Such treatment produces a working platform for construction or temporary roads, (NLA, 2004).

Lime in the form of quick lime (calcium oxide-CaO), hydrated lime (Calcium hydroxide-Ca $(OH)_2$), or lime slurry (a suspension of hydrated lime in water) can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone-$CaCO_3$) into calcium oxide. And hydrated lime is created when quick lime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix. Most lime used for soil treatment is "high calcium" lime, which contains no more than 5% magnesium oxide or hydroxide. On some occasions, however, "dolomitic" lime is used. Dolomitic lime contains 35 to 46% magnesium oxide or hydroxide. Dolomitic lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction. Soil stabilization significantly changes the characteristics of a soil to produce long-term permanent strength and stability, particularly with respect to the action of water and frost, (Ike, 2006).

Lime, either alone or in combination with other materials, can be used to treat a range of soil types. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine grained clay soils (with a minimum of 25% passing the #200 sieve (74mm) and a plasticity index greater than 10) are considered to be good candidates for stabilization, (NLA, 2004). Soils containing significant amounts of organic material (greater than about 1%) or sulphates (greater than 0.3%) may require additional lime and or special construction procedures.

a) **Lime stabilization for subgrade and subbase materials:** Lime can permanently stabilize fine-grained soil employed as a subgrade or subbase to create a layer with structured value in the pavement system. The treated soils may be in-place (subgrade) or borrow materials. Subgrade stabilization usually involves in-place road mixing and generally requires adding 3 to 6% lime by weight of the dry soil, (NLA, 2004).
b) **Lime stabilization for base materials:** Lime can permanently stabilize sub-marginal base materials, (such as clay-gravel, "dirty" gravels, limestones, calcite) that at least 50% coarse material retained on a #4 screen. Base stabilization is used for new road construction and reconstruction of worn-out roads, and generally requires adding 2 to 4% lime by weight of the dry soil, (NLA, 2004).

When quicklime is used for drying, it immediately hydrates (i.e., chemically combines with water) and releases heat. Soils are dried because water present in soil participates in this reaction and because the heat generated can evaporate additional moisture. During stabilization and when adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables the clay particles to break down. Determining the amount lime necessary is part of the design process and is approximated by tests such as the Eades and Grim test (ASTM D6276). Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). These are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of lime-stabilized soil layers, (NLA, 2004).

### 3.2. Soil reaction with cement

Cement stabilization of soil began with a trial on Salisbury plain in 1917. The cement acts as a binding agent within the soil matrix. In cement stabilization of soil, the soil is mixed with ordinary Portland cement and water, the mix is then compacted to improve the properties of the soil. Stabilization of soil with cement is a chemical method which is only second to mechanical stabilization in terms of importance and usage. Portland cement used commonly in cement stabilization of soil is made by heating limestone ($CaCO_3$) with small quantities of other materials (such as clay) to 1450$^oC$ in a kiln in a process known as calcination whereby a molecule of carbon dioxide is liberated from the CaCO3 to form calcium oxide, CaO or quicklime which is then blended with other materials.

The chemical composition of cement includes,
a) Tri-calcium silicate, $3CaO.SiO_2$
b) Di-calcium silicate, $2CaO.SiO_2$
c) Tri-calcium Aluminate, $3CaO.Al_2O_3$
d) Tetra-calcium Alumino Ferrite, $4CaO.Al_2O_3.Fe_2O_3$.

These chemical compositions of cement contribute to its adhesive and cohesive property which makes it capable of bonding fragments of minerals into a compact whole. When these chemical components in cement come in contact with the chemical components found in soil during engineering works on soil modification or stabilization, a chemical reaction ensues giving rise to stable or workable soil.

### 3.3. Soil reaction with bitumen

Bitumen is mixture of organic liquids that are highly viscous, black, sticky and entirely soluble in carbon disulphide, $CS_2$ and composed primarily of highly condensed polycyclic aromatic hydrocarbons, (www.wikipedia.com). Bituminous soil stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil material to form a stable base or wearing course. Bitumen increases the cohesive and load bearing capacity of the soil and renders it resistant to the action of water, (www.devilfinder.com). Stabilization of soil with bitumen differs greatly from cement stabilization. The basic mechanism involved in bitumen stabilization is a water proofing phenomenon. Soil particles are coated with bitumen that prevents or slows the penetration of water.

### 3.4. Soil reaction with the metal chloride compounds (KCl, $NaCl_2$, $MgCl_2$ etc.)

The addition of salts to soils increases the dry density and optimum moisture content as a result of the chemical reaction that takes place between the chlorides and the chemical components of the soils., (Wood, 1971). This behavior is attributed to the fact that at low moisture content, the soil structure (before compaction) tends to change from edge-to-face type of flocculation to face-to-face flocculation (salt flocculation) with increase in salt concentration, (Lambe, 1958).

## 4. CONCLUSIONS

It is obvious that the stabilization of soils (i.e., chemical stabilization) for engineering works is achieved through the chemical reaction (commonly exothermic reaction) that takes place between the chemical components of the soil and the stabilizers or modifiers. Results and experience show that lime as a chemical stabilizer is yields better results than the others but cement is commonly used because of its cost effectiveness. Though bitumen is constantly put to use during flexible pavement constructions because of its flexibility, it is not the cheapest. These stabilizers are used depending on the type of constructions.

It is recommended that geotechnical engineers consider the reactive effects of chemical stabilizers on the soil matrix before making the choice of any chemical method of stabilization.

## 5. ACKNOWLDGEMENTS

I express gratitude to the laboratory technologists and technicians of the Ministry of Works, Umuahia, Abia

State, Nigeria Soil Laboratory for their help and assistance.

## REFERENCES

Abood T.T., Kasa A.B. and Chik Z.B. 2007. Stabilization of Silty Clay Soil Using Chloride Compounds. Journal of Engineering, Science and Technology, Taylors University College, Malaysia. 2(1): 102-110.

Bureau of Reclamation. 1998. Earth Manual, 3rd Edition, Technical Science Center, Colorado, USA.

Ike C.C. 2006. Principles of soil Mechanics, De-Adroit Innovation, Enugu.

Lambe T.W. 1958. The Structure of Compacted Clay. Journal of Soil Machenics and Foundation, USA. 84, 55-70.

NLA. 2004. Lime Stabilization and Lime Modification, Lime-Treated Soil Construction Manual, Bulletin 326, USA. pp. 1-40.

Subramania M.S. 2011. Environmental Chemistry and Analysis, Module 5.2, Indian Institute of Technology, Madras. pp. 1-15.

US Soil Survey. 2011. Soil Properties, Woodruff County, Arkansas. pp. 1-4.

Wood K.B. 1971. Highway Engineering Handbook, Chapter 21. McGraw Hill Company Inc., New York, USA.

www.devilfinder.com. 2011. Effect of Bitumen on Soil Stabilization, January 6, 2011.

www.wikipedia.com. 2010. Properties of Bitumen, December 28.