STABILIZATION OF LATERITES WITH INDUSTRIAL WASTES: A RECENT AND COMPREHENSIVE REVIEW

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Abstract
Laterite is a soil and rock type rich in iron and aluminum, and is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of rusty red coloration, because of high iron oxide content. A lot of industrial waste such as baggasse ash, sugarcane ash, municipal solid waste, GRS, cold reclaimed asphalt (RAP), Aircanut coir, sawdust ash, ironstone, tyre ash, bio-enzyme, coconut shell/leaf asphalt ash, kernel shell and corncob ash. This shows that there is great potentials in industrial waste stabilization of laterites. Therefore a large scale stabilization with industrial waste should be embarked by various construction companies and agencies involved in road construction. Moreover, it can be used as a partial replacement for chemical stabilization in order to reduce the enormous cost of chemical stabilization.
Keywords: laterites, stabilization, industrial waste, review

1.0 Introduction

Laterite is a soil and rock type rich in iron and aluminum, and is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of rusty red coloration, because of high iron oxide content. Typical lateritics is porous and claylike. It contains the Iron oxide minerals, goethite ($HFeO_2$); lepidocrocite ($FeO[OH]$) and hematite(Fe_2O_2). It also contains titanium oxides and hydrated oxide of aluminum, the most common and abundant of which is gibbsite ($Al_2O_3.3H_2O$). The aluminum rich representive of lateritic are bauxites (Sinha, 2014).

They develop by intensive and long lasting weathering of the underlining parent rock. Tropical weathering or laterization is a process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. (Dalvi et al., 2004)..

Laterites are formed from the leaching of parent sedimentary rocks (Sandstones, Clays, limestones); metamorphic rocks (Schists, gneisses, peridotites); and mineralized proto ores

(Tardy, 1997), which leaves the more soluble ions, predominately iron and aluminium. The mechanisms of leaching involves acid dissolving the host mineral lattice, followed by hydrolysis and precipitation of insoluble oxides and sulphates of iron, aluminium and silica under high temperature conditions (Whittington & Muir, 2000) of humid sub-tropical climate (Hill et al., 2000). An essential feature for formation of lateritic soil is the repetition of wet and dry seasons (Yamaguchi, 2004). Rocks are leached by percolating rainwater during dry season. These ions form soluble salt compounds which dry on the surface; these salts are washed away during next wet season.

Lateritic formation is favoured in low topographical reliefs of gentle crests and plateaus which prevents erosion of the surface cover. The reaction zone where rocks are in contact with water from the lowest to highest water table levels is progressively depleted of the easily leached ions of sodium, potassium, calcium and magnesium. A solution of these ions can have the required pH to preferentially dissolve silicon oxide rather than the aluminium oxides and iron oxides

The mineralogical chemical compositions of laterites are dependent on their parent rocks. Laterites consist mainly of quartz, zircon and oxides of titanium, iron, tin, aluminium and manganese which remain during the course of weathering. Quartz is the most abundant relic mineral from the parent rock. Laterites vary significantly according to their location, climate and depth. The main host minerals for nickel and cobalt can be either iron oxides, clay minerals or manganese oxides. Iron oxides are derived from mafic igneous rocks and other iron rich rocks; bauxites and derived from granitic igneous rock and other iron deficient rocks. Nickel laterites occur in zones of the earth which experienced prolonged tropical weathering of ultramatic rocks, containing the ferro-magnesium minerals, olivine, pyroxene and amphobole.

Laterites are used: for upgrading degraded agricultural soils (ICRISAT, 2013), as a material for brick production (Engelhardt, 2010; Rock, 2009, Welch 2003; Uchida et al., 2003; Waragi et al., 2006 and Siedel, et al., 2008), as base and sub-base for road construction (Sari, 2004; Grace, 1991),for removal of phosphorus amnd heavy metals (Wood & McAtamney, 1996).

The values of common properties of laterites are given in table 1.1

Table 1.1: Some Common properties of Laterites.

PROPERTY	VALUE
Moisture Content (%)	10 – 19
Liquid limit (%)	33 – 90
Plastic Limit (%)	13 – 31
Clay Fraction (%)	14 – 45
Dry Unit Weight (KN/M^3)	15.2 – 17.3
Cohesion, Cu (Kpa)	466 – 782
Angle of internal friction	28 – 35
Unconfined compressive strength	220 – 623
Compression index	0.0186
Coefficient of consolidation (M^2/yr)	262 – 599
Young's modulus	5.63 x 10^4

Lateritic soils are of low to medium plasticity. The strength of lateritic may decrease with increasing depth beneath hardened crust. (Bells, 2005).

2.0 Mechanisms of Stabilization

In selecting stabilizer, it is of paramount importance to understand the behavior and mechanism of the stabilizer with the soil. The soil stabilization mechanism can be likened to coating and/or binding of soil particle to form another output soil with improved engineering behavior (Texas, DOT, 2005). The efficiency and effectiveness of the stabilizer depends upon the type of the soil to be stabilized, the type and properties of stabilizer, and the associated moisture content during compaction as well as long term moisture content. Furthermore, the effectiveness of stabilizer can be measured by its ability to donate calcium ion to chemical reaction. Lime, Portland cement and fly ash materials are the most frequently used chemical stabilizers. Fly ash that posses self-cementing property that can stabilize and treat soil without cement or lime are called class C fly ash whereas that often used either with lime or cement in order to make it more reactive is referred to as class F or non-cementing fly ash. The mechanisms of stabilization for these stabilizers is almost similar irrespective of few different processes. The overall stabilization process can be summarized into four different processes (Bhattacharja & Bwalty, 2003; Mallel et al., 2004).

The four processes are:-

Cation exchange

Flocculation and agglomeration

Cementitious hydration and

Pozzolanic reaction.

All the four processes mentioned above will occur in cement treated subgrade soils, whereas in case of lime treated soils cementitious hydration will be absent due to the lack of calcium aluminate hydrate (C-A-H) after hydration of stabilizer.

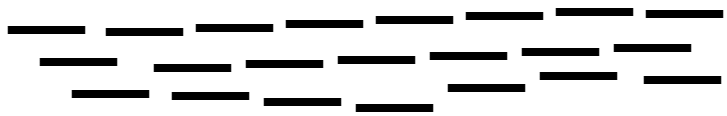
Cation exchange includes an immediate reaction of the clay with the stabilizer within few minutes of mixing, resulting in a soil with improved texture. The tetrahedral; (T) and Octahedral (O) or 2:1 (2T or IO) have charge deficiency that results in the attraction of the cations or water molecule. Generally, sodium or Potassium (Na^{+} or K) are prevalent in clay minerals along with water. However, these cations can be replaced by the higher valence cations like Al^{+3}, Ca^{+2}, Mg^{+2} etc in cation exchange. During this process calcium rich chemical stabilizer provides enough cations to replace the monovalent cations resulting in a reduced thickness of diffused double layer (Geiman, 2005). The calcium released in suspension of stabilizer-soil-water will be available for the stabilization of soil. The general reaction of the cement with water that yields calcium is shown in the equations below.

$$C_3S + H \longrightarrow C - S - H + Ca(OH)_2 \qquad 2.1$$

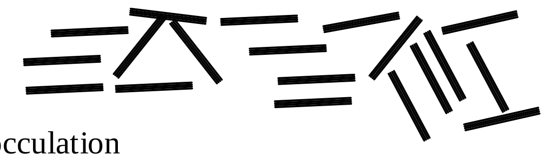
$$C_2S + H \longrightarrow C - S - H + Ca(OH)_2 \qquad 2.2$$

(Where H = H_2O, C = Ca, S = SiO_2, C_3S tri-calcium silicate, C_2S = di-calcium silicate and C – S – H = $C_3S_2H_3$).

Flocculation and agglomeration is the rearrangement of the clay particles from face to face orientation to more compact edge-face orientation (figure 2.1). The fine grained soil changes to the more coarse grained with much more improved strength/stiffness as well as workability (Al-Nukhtar et al, 2010; Brooks et al, 2010). As cation exchange, flocculation and agglomeration is also a short-term process, which takes place within few hours of mixing the stabilizer and water with subgrade soil.



(a) Unstabilied clay particles



(b)Clay after flocculation

Fig 2.1 Clay after flocculation/agglomeration of clay particle (Prusmki and BhattarCharya, 1999).

In addition to lime, cement contains calcium-aluminate-hydrate (C – A - H) that takes part in the further stabilization of the flocculated clay particles by yielding the glue like structure with calcium-silicate-hydrate (C – S – H). The strength provided by cementitious hydration in cement treated soil has extra strength as compared to any other treated/stabilized soils. The rapid gain in strength continues from the day of mixing till a month and may continue up to few years (Dhakal, 2012). In some cases, carbonation occurs in lime treated soils that is undesirable reaction at the start of stabilization because of formation of relatively insoluble carbonates rather than hydrates (Mallela et al, 2004).

Pozzolanic reaction is a long-term process that produces more stable hydrates and aluminates of calcium after few months of mixing of soil, stabilizer and water in order to maintain the pozzolanic reaction (Dhakal, 2012).

Fly ash stabilization of the soil is similar to that of cement ; however the resulting strength is less than the cement (Gautreau et al., 2009).

3.0 Industrial Waste Stabilization

Numerous research works have been carried out on stabilization of laterites. Moreover, we will look at recent work that has been done on stabilization of laterites to make them suitable especially as a material for highway construction.

Osinubi et al., (2009) worked on baggasse ash, stabilization of lateritic soil. Their study focused on the effect of up to 12% bagasse ash by weight of dry soil on the geotechnical properties of a deficient lateritic soil. The test specimens were subjected to particle size analysis, compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR) and durability tests. The compactions were carried out at the energy of the British Standard Light (BSL). A 2% bagasse, ash treatment of the lateritic soil yielded peak 7 days UCS and CBR values of 836KN/M^2 and 16%, respectively which are below 1,700KN/M^2 and 180% for UCS and CBR, respectively, recommended for adequate cement stabilization. It implies that bagasse ash cannot be used as a mono-stabilizer but should be employed in admixture stabilization, according to their findings.

Amu et al., (2011) worked on two geotechnical properties of lateritic soil stabilized shows that sugarcane straw ash. Their results show that sugarcane straw ash improved the geochemical properties of the soil samples,. Optimum moisture content increased from 19.0 to 20.5%, CBR from 6.31 to 23.3% and UCS from 79.64 to 284.66KN/M^2. They concluded that sugarcane straw ash is an effective stabilizer for lateritic soils. A similar work was also done by Oguribido (2011).

An investigation has been made into the compaction characteristics of lateritic soil stabilized Municipal Solid Waste (MSW) bottom sediment. The work was directed towards determining to what extent the results of the British Standard Compaction Test for lateritic soils are affected by

MSW bottom sediments. The bottom sediments of MSW from some selected dumping sites in Kano metropolis, Nigeria were mixed with lateritic soils in different proportions and a compaction tests was conducted on the mixtures were found to range between 1.6 and 1.7 Mg M^3 and optimum moisture content (OMC) were between 12% and 17%. The results are similar to those of silty clay soils of MDD between 1.6 and 1.845 and ONC between 15% and 25%. It is recommended that the bottom sediments be used as land fill or road construction material after sorting out re-cycled materials (Abdulfatah, et al., 2013).

Marto et al., (2013) investigated the stabilization of lateritic soil using GKS soil stabilizer. In order to understand the effects of GKS on the stabilization of laterite soil, laboratory tests on the unconfined compressive strength and shear strength of untreated and treated soil samples were formed. The results indicated that GKS (Liquid Polymer) is able to significantly increase the unconfined compressive strength and shear strength of laterite soil. The unconfined compressive strength increased with the duration of curing time, the variation namely occurring in the first 7days. The result also indicated that the stabilizer is worth using for practical projects such as road construction, backfilling, erosion control and for slope stability.

Amadi (2010) evaluated the changes in index properties of lateritic soil stabilized with fly ash. The objective of this study was to evaluate the changes in the index properties of a laterite stabilized with fly ash. Lateritic soil-fly ash mixtures with up to 20% fly ash by dry weight of soil were tested and specimens for compaction characteristics were prepared at different compaction states and compacted using British Standard Light (BSL) compactive effort, while soil-fly ash mixtures containing up to 15% fly ash classify as CL according to uses was used, it was observed that changes in the gradation characteristics of soil samples treated with 20% fly ash resulted in the alteration of its classification to ML. The liquid limit (LL) varied from 42.2 to

29.53% representing 70% reduction while the plasticity index (PI) of specimen treated with 2% fly ash was 10% lower than the natural soil. The optimum moisture content (OMC) ranged from 17.36% for the natural soil to 18.34% for soil mixtures containing 20% fly which yielded dry unit weight of 17.2KN/m^3 for samples treated with 20% fly ash. From the study, useful data were obtained showing substantial and desirable changes in the properties of lateritic soil as a civil engineering material on application of fly ash.

Mustapha, et al (2014), stabilized A-6 lateritic soil using cold reclaimed asphalt pavement (RAP). The RAP, in a cold state, was mixed with the lateritic soil at varying percentages of 0,5, 10 and 15. CBR and UCS were used as evaluation criteria for specimens of the soil-RAP mixtures, compacted at British Standard Heavy (BSH) energy level. The strength evaluation was carried out at 60% RAP mixture which was found to be the optimum RAP content that gave the highest MDD. Extraction test result on the RAP gave 7.3% bitumen content which is slightly higher than the 7.0% maximum recommended. There was 12.7% increase in MDD which occurred at 60% RAP content. The optimum moisture content (OMC) decreased by 31.3%. the result of CBR on the soil mixed with 60% RAP showed slightly increase of 7.2%, while 9.9% increase was recorded for the unconfined compressive strength.

Lekha et al (2015) stabilized lateritic soil with Arecanut and evaluated its performance as a low volume pavements. Their study focuses on the durability test and physical evaluation of soil cement mixtures reinforced with Arecanut coir. Coir content was varied from 0.2% to 1% with an increment of 0.2%. for further improvement, uniform dosage of 3% cement was added to soil, CBR, durability and fatigue behavior, were conducted. The test results indiacted that the improvement in characteristics of the soil cement coir mixtures were functions of coir dosage, soil type and curing days. Durability test satisfied at % 0.5 Arecanut coir with 3% cement.

Cement stabilized, Akwuete lateritic soil and the use of Bagasse Ash as admixture was studied by Onyelowe (2012). He stabilized the laterite using 4% and 6% cement with variations of bagasse ash ranging from 0%, 2%, 4%, 6%, 8% and 10% by weight of the dry soil. He investigated the effect of bagasse ash on the soil with respect to compaction characteristics and CBR tests. The result he obtained indicates a decrease in maximum dry density (MDD) with 4% cement content and an increase with 6% cement content. There is also an increase in optimum moisture content (OMC) for both 4% and 6% cement content. An increase was also recorded in the CBR of the soil. He concluded that bagasse ash can be used as admixture in cement stabilized lateritic soil.

Ogunribido (2012) studied the Geotechnical properties of Sawdust ash stabilized Southwestern Nigeria lateritic soils. The result of his study shows that Sawdust has improved geotechnical properties of the soil samples: maximum dry density increase from 1403 to 1456Kg/m^3, optimum moisture content increased from 23.6 to 28.2%, UCS from 101.40 to 142.14 and shear strength from 50.92 to 71.07KN/m^2. From his result he concluded that Sawdust ash is an effective stabilizer for lateritic soils.

Nwaiwu et al., (2006) studied the properties of ironstone lateritic Gravels in relation to gravel pavement construction. They conducted laboratory investigation to determine properties of ironstone lateritic gravels aggregates. Measured values of physiochemical, physio-mechanical as well as index properties and compaction characteristic are similar to those of other lateritic gravels occurring in West Africa which are used in road pavement application, they discovered that their basic geotechnical properties can be described using a third order polynomial function.

Modification of lateritic soil with lime and cement: An Economical Alternative for flexible pavement layer is a research work carried out by Portelinha et al (2012). They performed

Mechanistic analyses in order to verify fatigue failures on asphalt layers in roadways structural layer. Experimental results showed that addition of 2% and 3% of lime or cement was enough to change the soil workability and mechanical strength. In addition, they discovered that mechanistic analyses supported the soil modification technique as valuable practice with low elastic strains in the asphalt layer when applied in pavement base layers.

Consolidation properties of compacted lateritic soil stabilized with tyre ash were studied by Afolagboye and Talabi (2013). Assessment of the consolidation properties of compacted lateritic soil stabilized with up to 8% tyre ash were carried out using time dependent one dimensional consolidation test; to enhance the usage of the material in geotechnical engineering. The samples used were prepared at three different molding water contents and compacted using the modified American Association of State Transportation and Highway Official (AASHTO) compactive energy. The liquid limit, plasticity index, shrinkage limit and linear shrinkage of the lateritic soils were optimally improved on the addition of tyre ash. Preconsolidation pressure increased with tyre ash content but decreased with increasing moulding water content. Reductions in both the compression index (Cc) and swell index (Cs) were observed with increased in tyre ash content.

However, Cc increased with high molding water content while Cs decreased with higher molding water content. The coefficient of volume compressibility (Mv) decreased with increasing tyre ash content and consolidation pressure irrespective of the moulding water content. In addition, samples compacted on the dry side optimum moisture content (OMC) had the least Mv for all the pressure measurements. The coefficient of consolidation (Cv) decreased with increase in consolidation pressure and increase with increase in percentage tyre ash content in the three different moulding water content. Their study revealed that compressibility are influenced by the fabric and particle state of the soil.

Mithanaya (2008) et al performed the laboratory studies on Bio-Enzyme stabilized lateritic soil as a Highway Material. A road constructed with enzyme stabilized lateritic soil is monitored for its performance at regular interval for 8-10 months. The road perfumed well and field CBR test indicates that stabilized soil can be used as subbase material very effectively. They concluded the laboratory study is necessary to supplement good result in the field.

Soil sample collected from Maikunkele area of Minna, classified as an A-7-6 lateritic soil on AASHTO classification was stabilized with 2-12% rice husk ash (RHA) by weight of the dry soil. Using British Standard Light (BSL) compaction energy level, performance of the soil-RHA mixture was investigated with respect to compaction characteristics, CBR and UCS tests. The results obtained, indicates a general decrease in the maximum dry density (MDD) and increase in optimum moisture content (OMC) with increase in RHA content. There was also slight improvement in the CBR and UCS with increase in the RHA content. The peak UCS values were recorded at between 6-8%, indicating a little potential of using 6-8% RHA for strength improvement of A-7-6 lateritic soil (Alhassan, 2008).

Vysakh and Bindu (2012) stabilized lateritic soil using coconut shell, leaf and husk ash. After mixing the prepared coconut shell, leaf and husk ash with the collected lateritic soils, the consistency limit tests, engineering property tests and durability tests were done on both the stabilized and unstabilized states with the addition of various proportions of shell, leaf and husk ash (CSLHA) contents. The results show the addition of CSLHA improves the strength properties of soil. The optimum amount of CSLHA to be added for pavement construction is found to be 7%.

Effect of bagasse ash on lime stabilized lateritic soil was studied by Sadeeq et al (2015). The preliminary investigation carried out on the natural lateritic soil found in Shika, Kaduna state, Nigeria shows that it falls under silt-clay material group A-6 (9) using AASHTO and inorganic clay material CL according to Unified Soil Classification (USCS). The result obtained shows that the peak CBR value met the 20-30% requirement for sub-base, while the peak UCS value fell short of the 1710KN/m^2 unconfined compressive strength value specified by Transport and Road Research Laboratory (TRRL).

Ekeocha and Agwuncha (2014) evaluated palm kernel shells for use as stabilizing agents for use as stabilizing agents for lateritic soils. The scope of their work was limited to the strength characteristics such as the resilient properties, fracture or fatigue. Each of the composite mixes and the natural lateritic soil were subjected to percentages by weight of asphalt stabilization (2%, 4%, 6%, 8% and 10%), while PKS percentages of 25%, 50%, 75% and 100% by weight were used for the tests. Preliminary and strength were performed on the natural and composite mixes to determine their engineering behavior under laboratory conditions. The results showed that the addition of 25% PKS to the natural soil caused the Plasticity Index (PI) to increase to 19.0% and then subsequently reduce to 18.0% at 4% asphalt-stabilization. The addition of 5% asphalt to 75% lateritic and 25% PKS increased Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) to 1665kgm^{-3} and 23.6% respectively, with a reduction in average CBR to 1.15% (unsoaked) and 0.55% (soaked). With the same composite mix, the uncured compressive strength was 31.56KNm^{-2} while the cured was 931.62KN/m^2 and a shear resistance of 29.62KN/m^2 was recorded. Palm kernel shell alone was not able to stabilize the lateritic soils but when lateritic soil (75%) was mixed with PKS (25%) and the mix stabilized with 5% asphalt, there was improvement on the unconfined compressive strength.

Akinnwumi and Aidomojie (2015) studied the effect of Corncob ash on the geotechnical properties of lateritic soil stabilized with Portland cement. Their work aimed at providing experimental insights on the engineering properties of lateritic soil stabilized with cement-Corncob Ash (CCA) to ascertain its suitability for use as a pavement layer material. Series of specific gravity, consistency limits, compaction, CBR and permeability tests, considering three CCA blends and four CCA contents, varying from 0 to 12% were carried out. The results show that the addition of CCA to the soil generally reduced its plasticity, swell potential and permeability; and increased its strength. CCA-stabilization, aside being more economical and environment friendly than cement-Stabilization, improved the geotechnical properties of the soil for pavement layer material application.

Conclusion

A lot of industrial waste such as baggasse ash, sugarcane ash, municipal solid waste, GRS, cold reclaimed asphalt (RAP), Aircanut coir, sawdust ash, ironstone, tyre ash, bio-enzyme, coconut shell/leaf asphalt ash, kernel shell and corncob ash. This shows that there is great potentials in industrial waste stabilization of laterites. Therefore a large scale stabilization with industrial waste should be embarked by various construction companies and agencies involved in road construction. Moreover, it can be used as a partial replacement for chemical stabilization in order to reduce the enormous cost of chemical stabilization.

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