Chemical Stabilization of Lateritic Soils

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Abstract. Lateritic soils, a form of residual soil prevalent in tropical and subtropical regions, are frequently utilized in diverse construction applications such as roads, highways, buildings, railways, and airports due to their widespread availability. However, their natural geotechnical characteristics often fail to satisfy engineering design requirements, particularly with respect to consistency limits, shear strength, permeability, and compressibility. Consequently, property enhancement is frequently required prior to their use in construction. Chemical stabilization represents one of the most effective techniques for improving the geotechnical performance of lateritic soils. This process involves incorporating chemical additives that react with soil constituents to improve strength, durability, and overall performance. Over time, a variety of stabilizing agents including Portland cement, lime, fly ash, pozzolanic materials, polymers, and emulsified asphalt have been applied with varying degrees of effectiveness, depending on the soil's intrinsic properties and the intended engineering application. This study reviews and evaluates the efficiency of different chemical stabilizers in modifying the engineering behavior of lateritic soils, with particular focus on enhancing strength, reducing plasticity, improving durability, and increasing load-bearing capacity. A comprehensive understanding of the mechanisms and performance of these stabilizers is critical for optimizing the use of lateritic soils in infrastructure development, especially in regions where they constitute the primary construction material.

Keywords: Soil improvement; Geotechnical properties; Residual soil; Chemical additives; Soil stabilization.

1. INTRODUCTION

Lateritic soils are a distinctive group of highly weathered residual soils predominantly found in tropical and subtropical regions. They develop under hot and humid climatic conditions through intense and prolonged weathering of parent rocks, which leads to leaching of silica and enrichment of iron and aluminum oxides. Consequently, lateritic soils exhibit geotechnical characteristics that set them apart from other residual or transported soils. A comprehensive understanding of their properties is essential for infrastructure development in regions such as Africa, South America, Southeast Asia, and India, where these soils are widely distributed. In many cases, the natural properties of lateritic soils do not fully satisfy geotechnical design requirements, necessitating stabilization or modification. Stabilization methods are generally classified as mechanical, biological, or chemical. The choice of method depends on several factors, including the type, availability, and cost of the stabilizer, application techniques, curing time, as well as the intrinsic soil properties such as pH, organic content, mineralogy, degree of weathering, cation exchange capacity, and oxide ratios [1-4]. Lateritic soils form from the chemical weathering of igneous, metamorphic, or sedimentary rocks under conditions of high temperature and heavy rainfall. The leaching process removes soluble constituents, including silica, alkalis, and alkaline earths, while oxides of iron and aluminum accumulate [5-8]. This process imparts the characteristic red, yellow, or brown coloration and results in high iron and/or aluminum content. Typical minerals include gibbsite, goethite, and hematite, and the soils often exhibit blocky or pisolitic textures. Lateritic soils occur in two forms: indurated (hardened), commonly referred to as "ironstone," which is difficult to excavate but can serve as a construction material, and non-indurated (soft) soils, which are more common in geotechnical applications.

The Geotechnical Properties of lateritic soils are:

- Lateritic soils are often classified as sandy clays, clayey sands, or silty clays. The fine fraction primarily consists of kaolinite and oxides, with montmorillonite rarely present. Grain size distribution strongly influences permeability, compaction, and plasticity.
- These soils generally exhibit low to moderate plasticity, with plasticity index (PI) values between 10% and 25%. Due to the influence of iron and aluminum oxides, they may deviate from conventional plasticity correlations on the Casagrande chart.
- Lateritic soils typically display high shear strength, attributed to cementation by oxides, which enhances particle bonding. Cohesion values are often significant, and friction angles range from 25° to 40°. However, strength decreases under high moisture or disturbance due to the breakdown of cementation.
- They generally exhibit low to moderate compressibility, governed by soil structure and cementation. Initially resistant to deformation, lateritic soils may yield suddenly once oxide bonds fail. Long-term settlement is typically stable under undisturbed and drained conditions.
- Permeability varies widely depending on soil texture and cementation. Sandy laterites are relatively permeable, whereas fine-grained and indurated forms exhibit lower permeability and may act as aquicludes.
- Lateritic soils generally show minimal swelling and shrinkage, owing to the dominance of low-activity clays such as kaolinite and the stabilizing influence of oxides. Nonetheless, moisture fluctuations can still affect their volumetric stability.

The engineering challenges are:

- Lateritic soils exhibit significant variability in properties, complicated site characterization and design.
- To improve their suitability for subgrades, embankments, or foundations, stabilization with cement, lime, fly ash, or bitumen is often required.
- Weakly cemented soils are prone to erosion, particularly on exposed slopes, necessitating protective measures such as drainage control and vegetation cover.
- Indurated laterites can be extremely hard, sometimes requiring blasting, which increases construction costs and project timelines.

Despite these challenges, lateritic soils remain a valuable construction resource in tropical regions due to their abundance and potential for improvement through stabilization. Their engineering behavior is governed by unique mineralogy, oxide content, and degree of weathering. With proper characterization and treatment, lateritic soils can perform effectively in a wide range of geotechnical applications. A thorough understanding of their behavior is therefore crucial for achieving safe, economical, and sustainable infrastructure development in lateritic regions.

2. MATERIALS

2.1 Lateritic Soil

Lateritic soil is a general term for a group of residual soils that share common characteristics such as distinctive coloration, specific gravity range, dry density range, mineral composition, and parent rock origin, although they may differ in grain size distribution and plasticity. According to several authors [9-12], lateritic soils are highly weathered soils that occur in tropical and subtropical regions, characterized by silica leaching and depletion of light oxides such as Na_2O, K_2O, and MgO, while being enriched in Fe_2O_3 and Al_2O_3. Other researchers have defined lateritic soils based on the silica-to-sesquioxide ratio, expressed as $SiO_2/(Fe_2O_3 + Al_2O_3)$. When this ratio is less than 1.33, the soil is classified as laterite; between 1.33 and 2.0, as lateritic soil; and greater than 2.0, as non-lateritic soil [13-16]. In addition, climatic conditions have also been used as a basis for definition. Specifically, annual rainfall ranging between 750 and 3000 mm, and/or occurrence within tropical regions, has been associated with the formation of lateritic soils [15,17]. Color has also been widely employed as a descriptive criterion, with lateritic soils typically ranging from red to dark brown. Researchers often combine this color-based classification with the aforementioned geochemical and climatic definitions when identifying lateritic soils.

2.2 Mix Design

The use of chemical stabilizers in soil stabilization has involved a wide range of chemical agents applied at different percentages. However, to date, no fixed guidelines exist regarding the optimum dosage for each soil type, and the mix design process remains largely based on trial and error. ASTM standards provide references for cement (ASTM D2901-99), lime (ASTM D3155-98 and ASTM D3551-02), and fly ash (ASTM D5239-04), but do not specify recommended percentages for these additives across different soil types (ASTM, 2005). Consequently, researchers continue to experiment with varying proportions of these stabilizers in different applications. In addition, several new chemical agents have recently been introduced for soil stabilization, also applied using a trial-and-error approach to determine the optimum dosage and mixing techniques. A summary of previous studies employing various chemical stabilizers at different percentages for lateritic soils is presented in Table 1. Furthermore, the results presented in Table 1 indicate that the percentage of soil passing through sieve No. 200 does not significantly influence the required stabilizer dosage. Instead, the mineralogical composition of the soil plays a dominant role in determining the effectiveness and required percentage of the stabilizer, whereas particle size distribution has little to no effect.

Table 1. Review of previous studies on chemical stabilizers for lateritic soils.

Researchers	Stabilizers	Type	Ratio, percentage by weight	Recommended percentage	% Passing No. 200 sieve
Akoto & Singh [18]	Lime	Powder	0,3,5,7,10	7%	-
Rahman [19]	1-Lime 2- cement 3-RHA	Powder	1-0,2,4,6,8,10,12 2-0,2,4,6,8,10,12 3-0,4,8,12,16,20,24	5% 7% 18%	45.3
Osula [20]	Lime	Powder	0,1,2,3,	3%	55
Bell [21]	Lime	Powder	0,2,4,6,8,10	4-6%	100
Cassia de Brito et al. [22]	Lime	Powder	0,2,4,6,8	2-4%	94 and 67
Basha et al. [23]	1-Cement 2- RHA 3-cement-RHA	Powder	1- 0,2,4,8,12 2-0,5,10,15,20,25 3- [4:5,4:10,4:15,4:20,4:25 8:5,8:10,8:15,8:20,8:25]	6-8% cement 10-15% RHA and 4%cemnt +5%RHA	-
Mu’azu [24]	Cement- Bagasse ash mixture	Powder	1:2,1:4,1:6,1:8 2:2,2:4,2:6,2:8 3:2,3:4,3:6,3:8 4:2,4:4,4:6,4:8	4-6% Bagasse ash	63
Alhassan [25]	Lime – RHA mixture	Powder	2:2,2:4,2:6,2:8 4:2,4:4,4:6,4:8 6:2,6:4,6:6,6:8 8:2,8:4,8:6,8:8	4-6% RHA Up to 6%lime	62
Amu et al. [26]	Dissolved Alum	Liquid	0,5,10,15	Not effective on lateritic soil	-
Amu & Salami [14]	Eggshell and Eggshell: NaCl	Powder	0,6,10, 6:2,6:4,6:6,6:8,6:10, 10:2,10:4,10:6,10:8, 10:10	6:6 %	-
Okunade [27]	Coal Fly Ash (CFA)	Powder	2.5,5,7.5,10,12.5,15	12.5%	31-41
Eze-Uzomaka et al. [28]	Quarry dust – cement mixture	Powder	0:0,0:2,0:4,0:6,0:8,0:10 10:0,10:2,10:4,10:6,10:8,10:10 20:0,20:2,20:4,20:6,20:8,20:10 30:0,30:2,30:4,30:6,30:8,30:10 40:0,40:2,40:4,40:6,40:8,40:10 50:0,50:2,50:4,50:6,50:8,50:10	50:10	10
Amadi [29]	Fly ash	Powder	0,5,10,15,20	20%	40
Amadi [30]	Fly ash	Powder	0,5,10,15,20	5%	40
Eberemu [9]	RHA	powder	0,4,8,12,16	16%	-
Amu et al. [31]	Sugarcane Straw Ash (SSA)	Powder	0,2,4,6,8	4-8%	Silty
Ayininuola & Moody [32]	Cement – NaCl	Powder	10:0,10:1,10:3,10:5, 10:10	Up to 3%	-
Amu & Babajide [33]	lime – BLA	Powder	6:0,6:2,6:4,6:6 8:0,8:2,8:4,8:6	2-4% BLA	2-4
Mtallib & Bankole [11]	RHA – Lime mixture	Powder	0:0, 0:4, 0:6, 0:8, 0:10, 0:12 7.5:0,7.5:4,7.5:6,7.5:8, 7.5:10, 7.5:12 10:0,10:4,10:6,10:8,10:10,10:12 12.5:0,12.5:4,12.5:6, 12.5:8,12.5:10,12.5:12	12.5:6 %	0
Okonkwo et al. [13]	Cement – Eggshell–mixture	Powder	6:0,6:2,6:4,6:6,6:8,6:10 8:0,8:2,8:4,8:6,8:8,8:10	8:10	45.3
Henry & Ogunribido [10]	Saw dust ash	Powder	0,2,4,6,8,10	6%	43
Bello [34]	Lime	Powder	0,3,5,7,9	5%	59.2

2.3 Samples Preparation

Sample preparation procedures for lateritic soil stabilization studies do not follow a single standardized specification but rather vary depending on the researcher and the type of chemical stabilizer employed. In some cases, international standards such as the British Standard (BS) have been adopted [10-13,35-38]. Other studies have employed the ASTM (American Society for Testing and Materials) standards, sometimes with modifications to account for the unique characteristics of lateritic soils [13,22,27,34]. Similarly, the AASHTO (American Association of State Highway and Transportation Officials) specifications have been used for sample preparation and testing [14,19,20,25,27]. In addition, several studies have relied on national or regional standards. For example, the Indian Standard (IS) was employed by Ravi Shankarar et al. [39], Sunil et al. [40], and Sureban [38]; while the Chinese Standard was adopted by Shubber et al. [41], Yi et al. [42], and Zhu & Liu [43]. The Nigerian General Specification for Roads and Bridges (NGSRB) has also been widely applied, either alone or in combination with international standards [25,28,29,34]. In certain laboratory investigations, researchers have based their procedures on methodologies proposed in earlier studies rather than standardized specifications [16,21,42,44,45].

3. RESULTS AND DISCUSSION

3.1 Influence of Chemical Stabilizers on Index Properties of Lateritic Soil

Index properties are commonly used as primary indicators of soil strength, as they reflect the soil's capacity for water adsorption. A reduction in the plasticity index (PI) is generally considered evidence of improvement in soil behavior [46]. Chemical stabilizers influence the index properties of lateritic soils primarily by altering the liquid limit (LL) and plastic limit (PL). Most studies report a decrease in both LL and PL when soils are treated with different types of ash [26,29,31], as illustrated in Figure 1. Similar reductions in LL and PL were observed when dissolved alum was used as a stabilizer [31], and when dust and rock flour were incorporated [12,28]. Bio-enzyme stabilization also demonstrated a reduction in index properties with increasing enzyme dosage [39]. Conversely, studies using ashes such as coal fly ash (CFA), bamboo leaf ash (BLA), rice husk ash (RHA), sawdust ash (SDA), and bagasse ash (BA) reported a decrease in LL but an increase in PL [10,11,24], as shown in Figures 2 and 3. Comparable findings were obtained for lime stabilization of lateritic soils [8,20] Figure 4) and for gum stabilizers [37]. On the other hand, some researchers reported increases in both LL and PL with the use of various stabilizers [19,21,22]. Similar results were observed when cement–RHA mixtures were applied [23] or with RHA alone [9]. Other factors have also been shown to influence index properties. Soil pH directly affects LL, with acidic media increasing LL and alkaline media decreasing it [29,47]. Curing time has been reported to increase both LL and PL [11]. Furthermore, the clay fraction within the soil skeleton exerts a major influence on plasticity characteristics [39]. According to Whitlow's [48] classification based on LL (Table 2), lateritic soils can generally be evaluated as intermediate to high-plasticity soils, consistent with the data reported in previous studies.

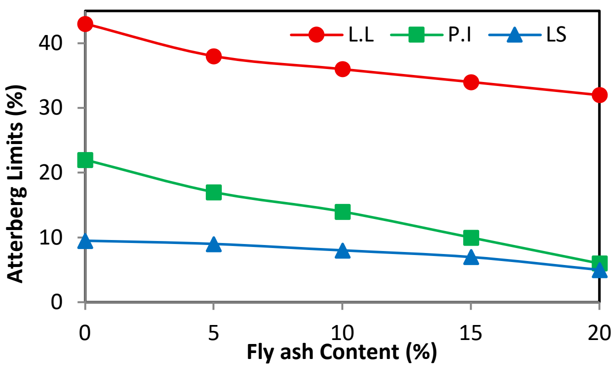


Figure 1. Relationship between Atterberg's limits and fly ash as a modifier.

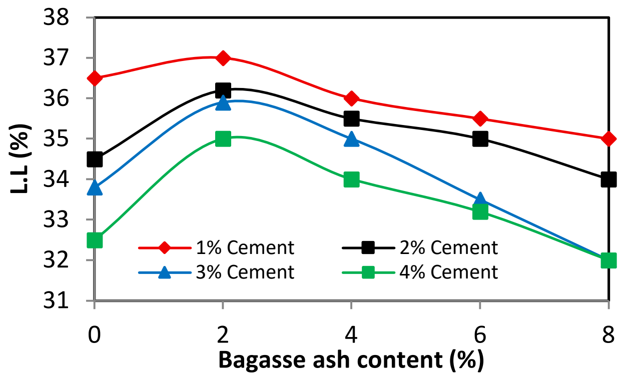


Figure 2. Effect of cement content with bagasse ash percent as a mixture on liquid limits.

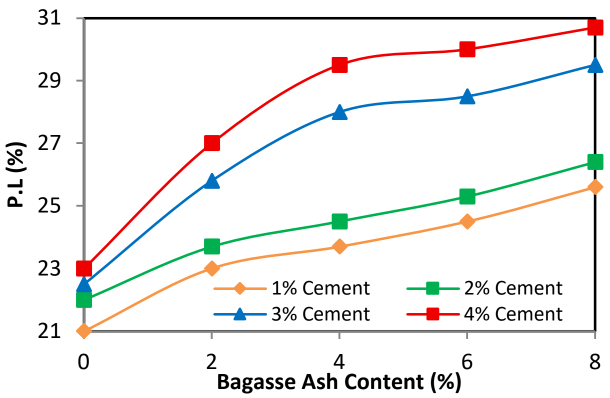


Figure 3. Effect of cement content with bagasse ash percent as a mixture on plastic limit.

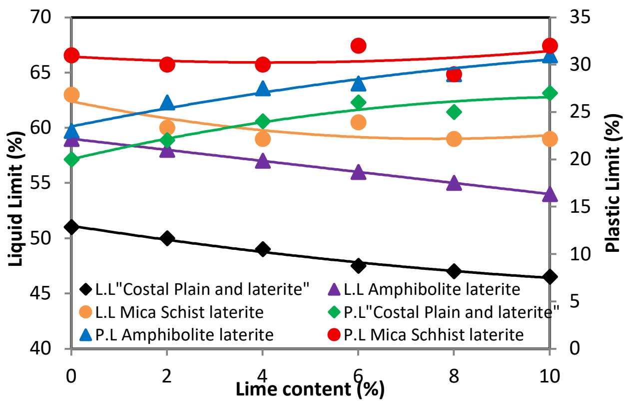


Figure 4. Effect of lime content on liquid and plastic limit of different soil types.

Table 2. Soil classification according to liquid limit (LL).

L.L, %	< 35	35 – 50	50 – 70	70-90
Description	Low plasticity	Intermediate plasticity	High plasticity	Very high plasticity

3.2 Influence of Chemical Stabilizers on Compaction Characteristics

Compaction characteristics are critical for geotechnical design and field applications, as they are closely related to soil strength and settlement behavior in earthworks. The compaction process provides two major benefits in the field: (i) reduction in post-construction settlement and (ii) enhancement of shear strength. In chemical stabilization, compaction parameters namely maximum dry density (MDD) and optimum moisture content (OMC) are often used as indicators of stabilization efficiency and to predict the interaction between stabilizers and soil minerals. The influence of chemical stabilizers on compaction behavior varies depending on both the type of stabilizer and the soil structure. Several studies [1,11,18-21,25] reported an increase in OMC and a corresponding decrease in MDD when lime was used as a stabilizer. This behavior is attributed to the flocculation and agglomeration of clay particles caused by cation exchange reactions, which reduce the soil's packing density. Similar trends were observed with other stabilizers such as fly ash (FA), spent catalyst stabilizing agent (SCSA), rice husk ash (RHA), gum Arabic, and emulsified stabilizing agent (ESA) [9,13,29,37]. These results were further explained by the relatively low density of some stabilizers and by pozzolanic reactions (Figure 5). In contrast, other stabilizers such as cement have been found to cause an increase in both MDD and OMC [13,19,28,49], as illustrated in Figure 6. Similar effects were observed when dissolved alum was used [26]. On the other hand, stabilizers such as groundnut shell ash (GSA), corn stalk husk ash (CSHA), eggshell salt mixtures, and bamboo leaf ash (BLA) demonstrated a different trend: an increase in MDD accompanied by a decrease in OMC (Figure 7a, b). This behavior is considered a favorable response for soil strength improvement. Researchers attributed it to flocculation and agglomeration, which reduce void volume, and to the formation of new compounds during stabilization. In addition, the porous nature of certain ashes enhances their water absorption capacity, thereby lowering the OMC required for compaction.

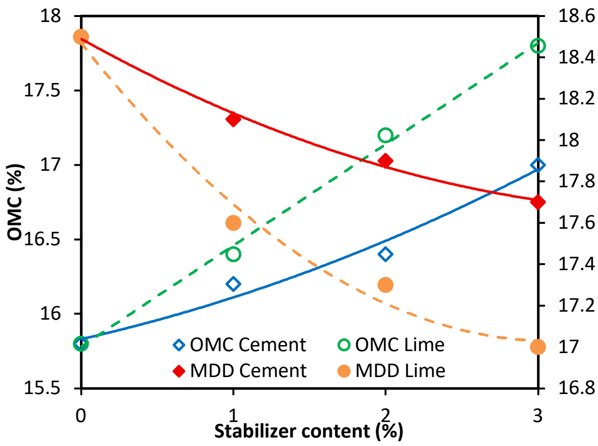


Figure 5. Effect of cement and lime stabilizers on compaction parameters

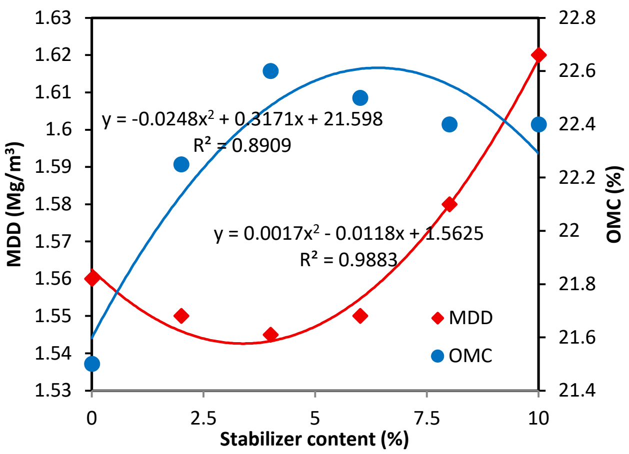


Figure 6. Effect different stabilizer content on compaction parameters

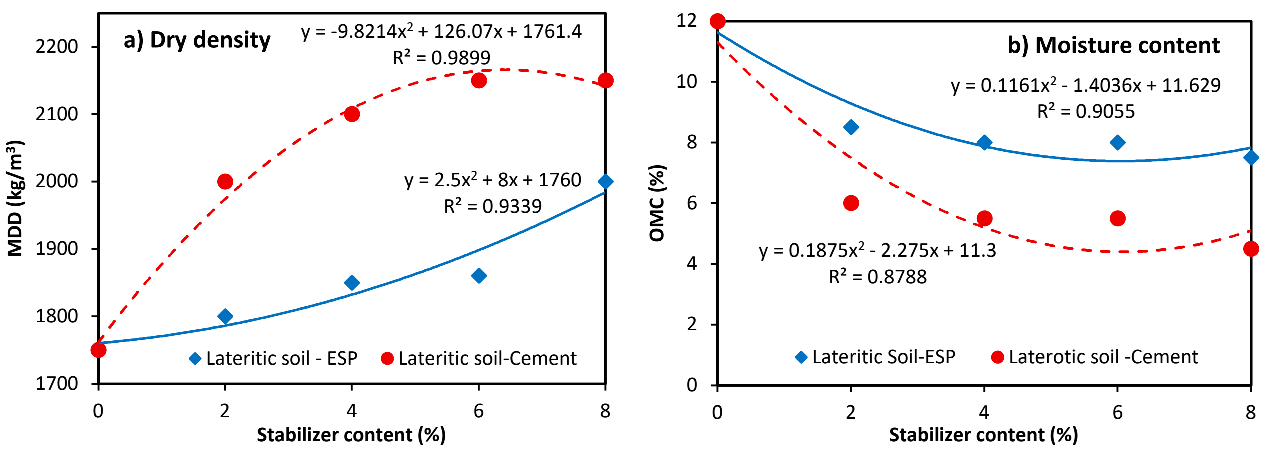
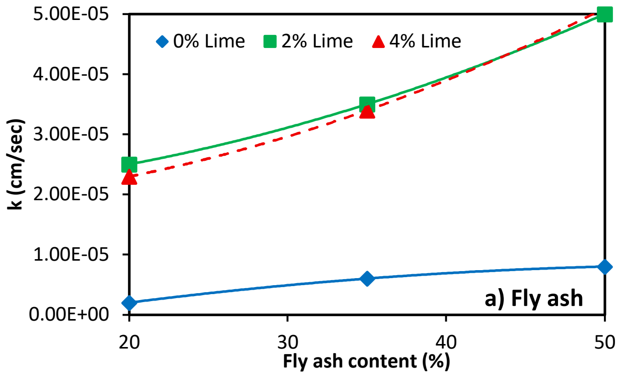


Figure 7. Dry density and moisture content of lateritic soil treated by chemical stabilizers.

3.3 Permeability Characteristics of Stabilized Lateritic Soil

Lateritic soils generally exhibit a permeability coefficient ranging from 10^{-4} to 10^{-11} m/s, depending primarily on their clay fraction and mineral composition [22]. Several studies have investigated how chemical stabilizers influence the permeability of lateritic soils. Goswami and Mahanta [50] reported that the permeability coefficient of lateritic soils increased when treated with lime and/or fly ash, as illustrated in Figure 8. Similar findings were observed by Flrat et al. [51] for different soil types treated with the same stabilizers. Conversely, Alhassan [25] observed a decrease in permeability when soils were stabilized with RHA and lime, particularly with increased curing time (Figure 9). Cassia de Brito et al. [22] emphasized that the effect of lime stabilization on permeability is strongly influenced by both soil type and clay fraction. In soils containing 20% clay, lime addition initially increased the permeability coefficient compared with untreated soil, followed by a decrease as lime content continued to rise. In contrast, for soils with 60% clay, the permeability coefficient consistently decreased as lime content increased. Other stabilizers showed distinct trends. Ravi Shankarar et al. [32] reported that the use of bio-enzymes reduced permeability, with the effect becoming more pronounced with higher dosages and longer curing times. Similarly, Amadi [52] demonstrated that permeability decreased as fly ash content increased, but beyond 10% fly ash, a sharp increase in permeability was recorded.



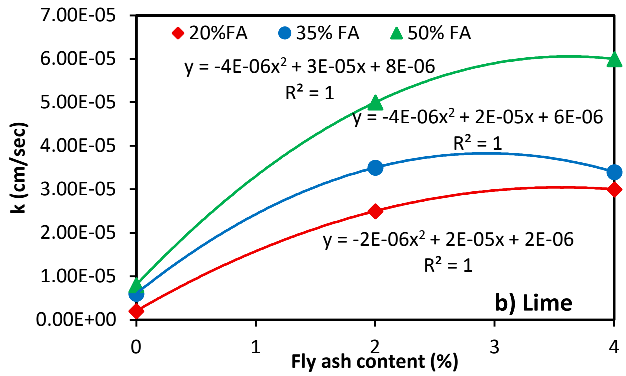


Figure 8. Effect of lime and fly ash mixture on the coefficient of permeability of laterite soil.

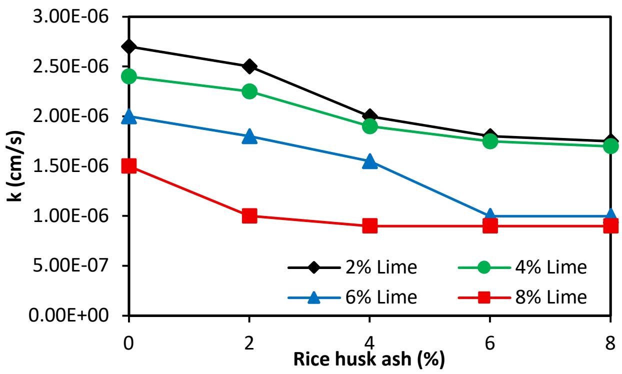


Figure 9. Effect of lime with rice husk ash mixture on permeability coefficient of laterite soil.

3.4 Unconfined Compressive Strength of Lateritic Soils

The unconfined compression test (UCS) is performed by applying a gradually increasing vertical load to a soil sample at a constant rate until failure occurs. The failure point represents the maximum compressive strength of the sample. Soil strength is influenced by both texture and water content [53]. Ola [54] reported that coarse-textured soils generally exhibit higher strength compared with fine-textured soils. Chemical stabilizers can enhance the UCS of soils by promoting flocculation and agglomeration, which effectively increase the coarse fraction of the soil and improve interparticle bonding. In addition, the water content and plasticity of the soil also significantly affect compressive strength, with higher water content generally reducing strength and higher plasticity modifying the soil's response to stabilization [55]. Table 3 summarizes the effects of various chemical stabilizers on the UCS of lateritic soils, illustrating how different additives and dosages influence soil strength [53-55]. The shear strength parameters, cohesion (c) and internal friction angle (ϕ), are commonly used to characterize soil strength and to evaluate the effect of chemical stabilizers. An increase in the internal friction angle generally reflects enhanced flocculation and agglomeration of soil particles and a reduction in clay-sized particles [20]. The type of stabilizer significantly influences these parameters. For example, lime and cement typically increase the internal friction angle while decreasing cohesion [46]. However, soil texture can modify this response. Amu and Babajide [33] observed that when three different soil types were treated with lime, two soils exhibited increased cohesion and decreased friction angle, whereas the third soil showed decreased cohesion and increased friction angle, highlighting the role of intrinsic soil properties. Ash-based stabilizers, such as various fly ashes, have been reported to increase both cohesion and friction angle in lateritic soils [26,33,46]. Conversely, dissolved alum caused reductions in both shear strength parameters when applied at different dosages [26]. Environmental factors can also affect shear strength. For instance, leaching of lateritic soils in landfill areas has been shown to increase cohesion while decreasing the friction angle [40]. The behavior of lateritic soils under different stress conditions is also noteworthy. Studies of the Mohr–Coulomb failure envelope indicate that it is curved at low normal stresses and approximately linear at higher stresses. This suggests that small confining pressures do not significantly affect shear stress because cementation bonds remain intact; under higher loads, these bonds are destroyed, and the soil behaves more like an uncemented material [56].

Table 3. Relationship between chemical modifiers and lateritic soil strength at different curing times.

Stabilizer	Recommended percentage, %	L.L, %	Curing time, days	UCS, kPa
Lime	4	40-55	7	600-750
Lime	4-10	40-55	28	600-1800
Cement	4 -10	38-50	7	600 - 4000
Different ash type	4-10	40-55	1	250-700
RHA	20	50	1	416
Baggass ash	4	93	14	935
Lime/RHA	8/8	45.5	7 28	1300 1800
Cement/eggshell	8/10	38	1	1000
Cement/fly ash	4/10	38 43 53	1 1 1	1700 1480 850
Bio–enzyme	4	35	7 28	428 782
Phosphoric acid	5	44 48 54	7	4320 4100 3900

3.5 California Bearing Ratio (CBR) of Stabilized Lateritic Soils

Table 4 summarizes the relationship between CBR and unconfined compressive strength (UCS) for various stabilizers applied to lateritic soils, highlighting the effect of specific gravity and soil type on bearing capacity [1,11,19,26,27,35,39,54]. The California Bearing Ratio (CBR) is a key parameter used to evaluate the suitability of stabilized soils for road construction and earth fill applications, providing an indication of soil strength and load-bearing capacity. Designers rely on CBR values to determine whether a soil is acceptable for specific pavement layers [35]. The CBR test involves measuring the penetration of a standard rod into a soil specimen contained in a standard CBR mold. The CBR value is calculated based on measurements at two penetration depths (2.5 mm and 5 mm), and the average of these values is expressed as a percentage. According

Table 4. Effect of different stabilizers on the strength of lateritic soils.

Recommended percentage, %	Soil name	CBR, %	MDD, kN/m^3	UCS, kPa	Specific gravity
8% lime 8% lime 8% lime	Santasi soil Ahodow soil Ahinsan soil	60 58 75	19.0 19.5 18.5	1550 2000 1300	2.68 2.65 2.7
0% stabilizer 3% lime 3% cement	-	43 85 220	21.7 20.6 20.1	650 1300 3000	-
4% lime	-	95		700	-
4% lime 10%cement 20% RHA	-	59.4 141 77.7	15.2 16.15 13.85	601.2 1515 416	2.64
10% cement	-	190	20.5	4000	2.58
8/10 % cement/Eggshell	-	92	16.6	1000	2.75
2% Bagasse ash	-	16	19.4	820	2.62
6% Sugar cane straw ash (SCSA) 4% SCSA 4%SCSA	A B C	23.3 8.42 24.9	19.85 18.8 17.9	284.7 227 472	2.42 2.58 2.68
4% Ground shell ash		4.2	15.5	950	-

to design guidelines, an 80% CBR at British Standard Light (BSL) in a standard mold is recommended for base and sub-base layers, whereas CBR ≥ 45% is typically sufficient for minor roads and CBR ≥ 65% for major or urban roads [11]. CBR values are strongly influenced by soil texture and mineral composition. Fine-grained lateritic soils generally exhibit CBR values ranging from 1% to 25%, whereas coarse-textured lateritic soils can exhibit CBR values between 30% and 85% [15,28].

4. CONCLUSIONS

This paper aims to explore the consistency and variability of results in chemical stabilization of lateritic soils within geotechnical engineering practices. Generalizing outcomes remains challenging due to the wide variety of chemical stabilizers used and the diverse textures and mineral compositions of lateritic soils. Moreover, the performance of chemical stabilizers can be influenced by environmental conditions, curing time, test methods, and the form or state of the stabilizer. Based on a review of experimental studies conducted by various researchers, the following conclusions can be drawn:

- Approximately 90% of stabilizers used in lateritic soil stabilization are in powder form, while 10% are liquid. Among powder stabilizers, ash-based materials constitute 33.3%, lime 30%, cement 26.7%, and other materials 10%. Currently, the use of ash and alternative stabilizers is increasing, whereas traditional stabilizers such as lime and cement are decreasing in prevalence.
- There is no universally fixed dosage for chemical stabilizers. The optimal percentage depends not only on the type of additive but also on soil texture and the intended engineering application.
- The increase in unconfined compressive strength is influenced by the liquid limit of the soil for the same stabilizer type, as well as by curing time. Liquid stabilizers generally have a greater effect on soil strength compared with powder or ash-based stabilizers.
- The California Bearing Ratio (CBR) is affected by the specific gravity of the soil for a given stabilizer, while the maximum dry density (MDD) has little impact on CBR but significantly affects UCS. Interestingly, no consistent correlation between CBR and UCS was observed for soils treated with the same stabilizer, highlighting the complex interaction between soil properties and chemical additives.

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