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Original Article

Performance of Rice Husk Ash- and Cement- Stabilized Lateritic Soils for Pavement Base Courses: A Case Study from Benin

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Abstract - *This study investigates the influence of partial replacement of cement with Rice Husk Ash (RHA) on the stabilization of lateritic soils for potential application as pavement base materials. Seven lateritic soil samples (A, B, C, D, E, F, and G) were characterized using a series of geotechnical and mineralogical tests, including Atterberg limits, standard Proctor compaction, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and X-Ray Diffraction (XRD) analysis. The rice husk ash was examined through Thermogravimetric analysis (TG) coupled with Differential Thermogravimetry (DTG) and X-Ray Diffraction (XRD) to assess its physicochemical and mineralogical properties. Then, the stabilization of the lateritic soil samples was carried out with Portland cement. Each sample of soil-cement was subjected to compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) tests for assessing the optimum cement content. Results show that CBR and UCS values increase with increasing cement content up to an optimum cement content, above which CBR and UCS decrease or slightly increase. The maximum dry density decreases with increasing cement content due to the increasing fine particles in the mix. The second stabilization involved partially and gradually replacing the optimum cement content with RHA. CBR value of 217% (≥ 160% in accordance with pavement design guideline CEBTP) and UCS value of 3 MPa (1.5-3MPa for UCS value after 7 days curing in accordance with pavement design guideline CEBTP) for the mix containing 95% soil F +3.5% cement +1.5% RHA were obtained. Also, CBR value of 165% (≥ 160% in accordance with pavement design guideline CEBTP) and UCS value of 2.5 MPa (1.5-3MPa for UCS value after 7 days curing in accordance with pavement design guideline CEBTP) for the mix containing 96% soil, G +3% cement +1% RHA were obtained. These findings indicate that Rice Husk Ash (RHA) can effectively serve as a partial replacement for cement in lateritic soil stabilization, making it suitable for constructing road bases in compliance with CEBTP specifications.*

Keywords - *Laterite soils, Rice Husk Ash, Cement, Stabilization, Pavement.*

1. Introduction

Reducing Greenhouse Gas (GHG) emissions is a major concern in the fight against climate change. Many countries have adopted policies and measures aimed at reducing these emissions, focusing particularly on transitioning to the expansion of renewable energy, optimization of energy efficiency, and promotion of sustainable mobility solutions and environmentally friendly agricultural practices. It is worth noting that most current research and innovation projects are focused on developing solutions to minimize GHG production, especially Carbon Dioxide (CO_2). In the civil engineering sector, cement production by manufacturing industries and the construction sector is the primary source of CO_2 emissions, since cement has become an essential material for construction. In response, research is underway to explore alternative binders to Portland cement, particularly focusing on recyclable materials of natural origin and biogenic by-products from agriculture, including Rice Husk Ash (RHA). On the other hand, the high cost of pavement construction and maintenance generally imposes a negative impact on the economic development of developing countries. These countries often exhibit poorly developed road networks, primarily due to the high incidence and frequency of pavement failures resulting from the use of low-quality soil materials. One potential solution is the development of alternative strategies to enhance the engineering properties of locally available in-situ materials, thereby reducing transportation costs and improving pavement performance. Studies have shown that rice husk ash can contain between 84% and 97% silica, exhibiting high pozzolanic reactivity (Sore et al., 2018) [1]. When used as an additive or substitute in Portland cement, RHA can enhance the mechanical properties of ordinary concrete. Over the years, research has extended to the field of road construction, exploring the potential use of rice husk ash in pavement courses. Such improvement can be achieved through the stabilization of in-situ soils using agricultural by-products, followed by compaction to attain the required strength. This approach not only enhances the engineering properties of the soil but also contributes to reducing environmental pollution from agricultural waste and mitigating greenhouse gas emissions.

The primary research question is whether Rice Husk Ash (RHA) could reduce cement usage in road construction. This study focuses on evaluating the use of RHA as a pozzolanic material, considering its partial replacement of cement in treating laterite soils for road construction. Its use could reduce the amount of cement required and thus lower the cost of road construction. Environmentally, in addition to reducing GHG emissions, it limits the disposal of rice husks in nature, where they often go unutilized. Sometimes, rice husk disposal is burnt, releasing GHGs such as Carbon Dioxide (CO2) and Methane gas (CH_4). Initial research has evaluated the properties of rice husk ash as a cement substitute (Habeeb et al. 2010 [2]). Botchway et al. (2020) [3] determined the optimum percentage of Ghanaian RHA to partially replace Ordinary Portland Cement (OPC) to improve concrete compressive strength. Previous Study investigated the effect of the stabilization of laterite soils with cement on the geotechnical properties of these soils. As a result, the cement improves the geotechnical properties up to an optimum cement content, above which these geotechnical properties drop.

One of the researcher identified that rice husk ash, which primarily contains 84%- 97% silica, exhibits high pozzolanic reactivity and is suitable for use as a pozzolanic filler material in Portland cement to improve the mechanical properties of ordinary concrete, like fly ash or silica fume. Studies have also noted that RHA particles are significantly finer than cement particles. Over time, research has extended to the field of pavements. Sargin et al. (2013) [4] demonstrated that rice husk ash could be used as a mineral-based filler material in asphalt concrete mixtures. Other researchers have explored using RHA for soil treatment in pavement layers, such as a study on the consolidation properties of compacted laterite soil treated with RHA in the Shika region of Nigeria, Eberemu et al. (2011) [5]. Encouraging results have been reported by Somnath Paul et al. 2022 [7] and Ramadhan et al. (2020) [8], with an optimal dosage of 6% RHA for a locally available laterite soil in northeast India. Similarly, Baimourne et al. (2023) [6] identified an optimum mixture of 5% cement and 3% RHA, achieving a soaked California Bearing Ratio (CBR) of 115% and an unconfined compressive strength of 1.72 MPa for a clay-rich laterite soil, compared to a cement-only treatment requiring 8% cement.

Basha et al. (2015) [9] conducted a similar study on a granitic soil in Malaysia, showing that a combined treatment with cement and rice husk ash achieved a maximum CBR of 60% with a dosage of 4% cement and 5% RHA. Dabou et al. (2021) [10] investigated the impact of partially replacing cement with Blue Gumwood Ash (BGWA) for stabilizing laterite soil, to evaluate its performance as a material for road base construction. The stabilization of laterite soil from Kenya was achieved by partially replacing 6% cement content with BGWA, reducing the replacement level in increments of 1%. The highest California Bearing Ratio (CBR) value of 348% was recorded at 2% BGWA content, significantly exceeding the 160% threshold recommended by the Kenya Road Design Manual. Additionally, an Unconfined Compressive Strength (UCS) value of 2.99 MPa was achieved after 7 days of curing. Therefore, BGWA can serve as a partial substitute for cement in stabilizing laterite soil, meeting the requirements for road base construction outlined in the Kenyan Road specifications. Despite this growing body of evidence regarding the performance of RHA-stabilized soil, three gaps remain relevant to West African practice and to Benin in particular.

- Base-course performance evidence is limited. Much of the RHA–soil literature focuses on subgrade/subbase behaviour (plasticity, compaction, CBR) rather than on base-course performance.
- Context-specific data for Benin laterites are scarce. However, the engineering behaviour of laterite soils varies strongly with parent rock and pedogenesis, leading to moisture sensitivity, high plasticity, and insufficient strength for base-course duty unless properly treated. While Beninese laterites are abundant and used broadly in construction, systematic stabilization data for local laterites with cement–RHA blends and benchmarking to base-course design thresholds remain under-reported.
- Process variability of RHA is under-controlled. Reported performance scatter is often tied to ash production (burning temperature/time, carbon content, fineness), yet many studies provide limited characterization, complicating the transfer of optimum dosages across regions and supply chains.

Against this backdrop, the present study evaluates the performance of a Benin lateritic soil stabilized with cement and rice husk ash for pavement base-course application, addressing the three gaps above. Specifically, we generate (i) a Benin-specific dataset for cement–RHA–laterite mixes, (ii) benchmark UCS and CBR (soaked/unsoaked) against recognized CEBTP practice ranges to judge base-course suitability. By situating the findings alongside classical residual-soil stabilization with cement–RHA (e.g., Basha et al. 2015 [9], Manaviparast et al. 2025) [22] and recent reviews highlighting beneficial dosage windows and failure modes at high RHA contents, the study provides practice-oriented evidence base tailored to Benin's material context and supply realities, which is a valuable contribution to sustainable construction and aligns with efforts to reduce greenhouse gas emissions in developing countries like Benin.

2. Materials and Methods

2.1. Materials

The samples of laterite soils were gathered from borrow pits in the districts of Pobè, Kétou and Abomey in the southern part of the Republic of Benin (located between latitudes 6° 25' and 12° 30N and longitudes 0° 45' and 4°E). The sample name, location and geographic coordinates are given in Table 1. The locations are potentially an important quarry of lateritic soil for road construction.

Table 1. Name, location and geographic coordinate of laterite soils tested

N°	Sample	Location	Geographic coordinates
1	A	Akpotokou (Idigny)	7°36'43"N, 2°38'33"E
2	B	Illéchin (Idigny)	7°37'29"N, 2°41'10"E
3	C	Illadji	7°32'39"N 2°36'15"E
4	D	Omou-Ewè (Kétou)	7°35'14"N, 2°39'46"E
5	E	Ossokodjo (Kétou)	7°21'7"N, 2°36'51"E
7	F	Mougnon (Abomey)	7°13'42.92"N, 1°59'38.67"E
8	G	Illoulofin (Onigbolo)	7°16'96.2"N, 2°67'23.2"E

The top 0.50 m of soil was excavated to remove the organic-rich layer. Lateritic soil was subsequently collected from the A horizon, which had an approximate thickness of 2.5 m. The samples were carefully packed in jute bags and transported to the laboratory for testing. Previous geological and pedological investigations indicate that the collected soils are classified as ferritic tropical soils, derived from the weathering of acidic igneous and metamorphic rocks.

The cement employed in this study is a compound Portland cement (CPJ-CEM II/B 32.5), predominantly composed of Portland clinker, limestone, granulated blast furnace slag, and siliceous fly ash, with a clinker content ranging from 65% to 79%. It is produced in the Republic of Benin. The choice of this cement was based on its common use in sub-Saharan Africa, particularly in Benin, for pavement construction, where CPJ 32.5 cement is widely utilized.

On the other hand, compound Portland cement (CEM II) is becoming increasingly popular for soil stabilization, replacing traditional Portland cement. Its chemical composition and some specifications are provided in Table 2. Tap water at a temperature of about 25°C was used for the experimental tests. The rice husk was collected from the rice husk disposal near the rice factory of Zinvé in the district of Abomey-Calavi in Benin. This factory separates the edible rice grains from their husks, which are discarded in the disposal. The collected rice husks were washed to eliminate organic matter and debris. The clean rice husks are then crushed into fine particles and passed through a 400 mm sieve to obtain the Rice Husk Powder (RHP), which is then calcined to obtain the Rice Husk Ash (RHA).

2.2. Methods

The laterite soils were first characterized. For the physical characterization of the laterite soils, the following identification tests were carried: moisture content (NF EN ISO 17892-1, (BS EN ISO 17892-12, 2018)), sieve analysis (NF EN ISO 17892-4, (EN ISO 17892-10: 2018)), Atterberg limits (allowing the determination of the Plasticity Index NF EN ISO 17892-12, (CEN ISO TS 17892 1: 2014), and methylene-blue absorption test (EN 933-9), Proctor compaction test, soaked California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS).

Additionally, laterite soil samples, cement and rice husk ash were subjected to X-Ray Fluorescence (DRX) test to determine their chemical composition. The test was conducted at the research centre SEME CITY in the Republic of Benin. Moreover, RHP was subjected to combined Thermogravimetry (TG) and Differential (DTG) to determine the optimum calcination temperature at which the Rice Husk Ash (RHA) presented an amorphous chemical compound (no crystalline form of chemical compound), which can react with the chemical compounds of laterite soil and cement.

Then, laterite soils were stabilized with Portland cement and the physical and mechanical properties of stabilized soils, such as Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Axial Strength (UCS) were determined.

Based on the values of these properties, the optimum cement content to fulfil the requirement of the road design guideline CEBTP for tropical countries was derived. This optimum cement content was progressively substituted by rice husk ash to save cement and reduce greenhouse gases in pavement construction.

The laterite soils were further stabilized, replacing optimum cement content with RHA. For that, RHA gradually replaced the cement content, starting from the optimum cement content. The stabilized soil samples were then subjected to compaction, CBR and UCS tests for determining the physical and mechanical properties of that geocomposite (laterite soil + cement + rice husk ash). Figure 1 presents a simplified graphical illustration of the applied methodology.

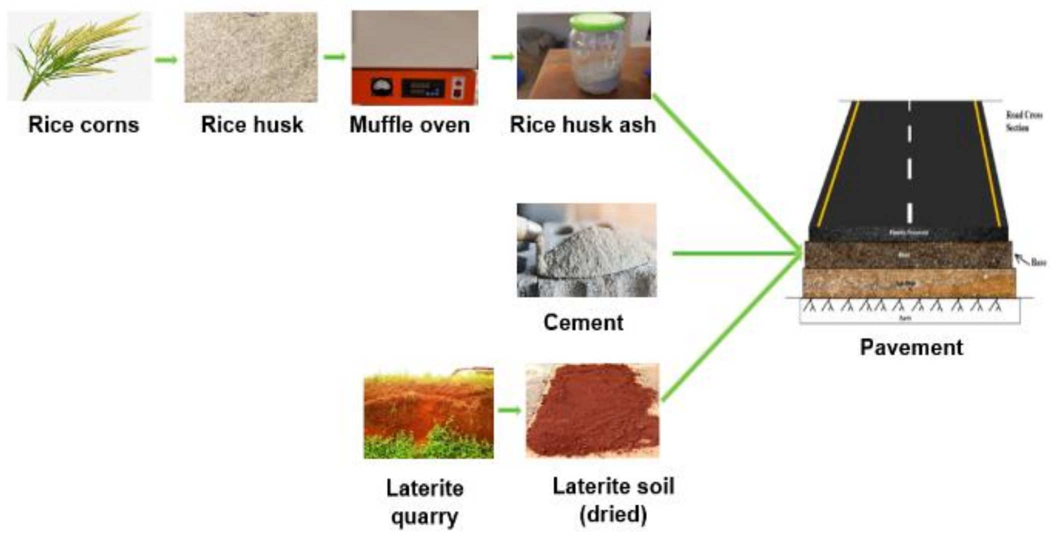

Fig. 1 Simplified graphical illustration of methodology

3. Results and Discussion

This section presents the results analysis and discussions of the physical performance (grain size distribution, plasticity index, Proctor compaction, Thermogravimetry (TG) and differential (DTG), X-ray diffraction), and the mechanical performance (density, CBR, UCS) of cement-stabilized laterite soil and RHA-cement-stabilized laterite soil.

3.1. Physical Analysis

Figure 2 presents the grain size distribution curves of the laterite soils tested as a result of the sieve analysis. The soils consist of wide-graded clayey and silty sand with about 20% of gravel. The soil classification in accordance with NF EN ISO 17892-4 (EN ISO 17892-10: 2018) shows that the laterite soils tested are of class B3 to B6. The grain size distribution curves lie within the lower and upper bound curves for the base course specified by the road guideline CEBTP [11]. Therefore, the laterite soils tested can be used for the base course for pavement. Based on the particle size distribution shown in Figure 2, the laterite soils contain approximately 20% gravel, 60% sand, 10% silt and 10% clay.

Figure 3 shows the tested laterite soils in the plasticity diagram as per Casagrande. The soils were close to the A line, were little to medium plastic clay with plasticity index between 5 and 20%, and liquid limit between 25 and 50%. Figure 4 shows the results of the Proctor compaction test for the laterite soils tested. The soil D showed the largest dry density and the minimum optimum water content. On the contrary, the soil F showed the smallest dry density and the minimum optimum water content. The largest fine fraction of the laterite soil D and the smallest fine fraction of the soil F can explain the above-mentioned behaviour regarding the compaction behaviour. Indeed, the fine fraction migrates to the pore generated by the matrix of large grains, leading to more compacted soil and therefore a large dry density. The soils A and B showed similar optimum water content. However, the optimum density of soil B (2.24 t/m3) is slightly larger than the optimum density of soil A (2.21 t/m3). The soils C and E presented similar optimum water content (approximately 9.60 %); however, the optimum density of soil C (2.21 t/m3) is slightly larger than the optimum density of soil E (2.19 t/m3). The soils A and B had a similar behaviour related to compaction tests, whereas the soils D and E had a similar behaviour related to proctor tests. The suitability of the soils to be used for the base course for pavement was verified in accordance with the road design guideline [11]. Laterite soils C, D, E were suitable for the base course of a pavement in accordance with the road design guideline [11]. However, raw laterite soils A, B, E, G, and F were not suitable for base course and needed to be stabilised with binder before use.

3.2. Thermogravimetry (TG) and Differential Thermogravimetry (DTG) Analysis

For the determination of the optimum calcination temperature, RHP was subjected to combined Thermogravimetry (TG) and Differential Thermogravimetry (DTG). Figure 5 shows the curves of the thermal degradation characteristics of RHP at a heating rate of 10°C/min. Thermogravimetric analysis of the lignocellulosic biomass revealed distinct regions of thermal decomposition. The initial stage, below 120 °C, corresponds to the removal of moisture and light volatile components. Hemicellulose degradation occurs between 220 °C and 315 °C, followed by the decomposition of cellulose and lignin within the 315–400 °C range. Residual lignin undergoes progressive breakdown at temperatures above 450 °C. These distinct thermal events highlight the complex composition of the biomass and provide critical insight into its potential reactivity when used as a supplementary pozzolanic material., Sanchez-Silva et al (2012), Yang et al (2007) [12, 13]. Lignin exhibits a slow thermal decomposition over a wide temperature range, spanning 180–900 °C. As illustrated in Figure 5, the initial phase of weight loss corresponds to moisture evaporation and the release of highly volatile compounds, followed by a subsequent stage, termed devolatilization, which initiates at approximately 240 °C for rice husk powder.

The majority of devolatilization occurs during this second weight-loss phase and is attributed to the thermal cleavage of labile chemical bonds within the polymeric matrix of the biomass constituents, leading to the formation of more stable and thermally resistant chemical structures, Roque-Diaz et al (1985) [14]. Lignocellulosic biomasses, such as rice husks, are primarily composed of hemicelluloses, cellulose, and lignin. The devolatilization phase predominantly corresponds to the thermal decomposition of these structural components, Biagini et al. (2006) [15].

In the Derivative Thermogravimetric (DTG) curves, the temperatures corresponding to the maximum rates of mass loss are indicated by the positions of the peaks. For rice husk materials, the DTG curve during the devolatilization stage exhibits distinct peaks, which correspond to pronounced changes in the slope of the Thermogravimetric (TG) curve.

Considering the characteristic decomposition temperature ranges of the main lignocellulosic components, the observed DTG peaks for rice husk powder can be interpreted as follows: the first peak at approximately 120 °C is likely associated with the thermal degradation of hemicelluloses, while the second peak at around 440 °C corresponds to the decomposition of cellulose. Hereby, the first and second peaks are well distinct, which can be explained with high about 20% of ash content of RHP, Antal and Varhegyi (1995) [16]. The third stage is characterized by a significantly lower rate of mass loss compared to the second stage.

This phase corresponds to the completion of cellulose decomposition, followed by the thermal degradation of heavier volatile compounds, cleavage of Carbon-Carbon (C-C) bonds, and the formation of amorphous silica, which exhibits high pozzolanic reactivity. For temperatures larger than 800°C, crystalline quartz that has poor reaction activity with other chemical compounds will be formed. Therefore, the decarbonation of rice husk powder was carried out at 800°C.

3.3. X-Ray Diffraction Analysis

The result of X-ray diffraction for laterite soil G is shown in Figure 6. The diffractogram indicates that the main chemical compounds (minerals) of this laterite soil are silicate oxide (quartz), aluminium oxide (alumina) and iron oxide (iron). Using the EVA software, the relative abundance of each identified mineral was estimated semi-quantitatively by analysing the net area of the peaks in the diffraction pattern (Table 2).

The diffractogram for RHA indicated that the main mineral of RHA is quartz (Figure 7), and the percentage of the minerals is given in Table 2. These mineral phases are those commonly present in laterites, as reported by Sore et al. (2018) [1] and Millogo et al. (2008) [17].

Table 2. Physical and chemical properties of lateritic soil, cement and RHA

	Physical tests		Chemical compositions (%)										Bogue compositions (%)			
	Specific gravity (g/cm^3)	Blaine (cm^3/g	SiO_2	Al_2O_3	Ti_2O	Fe_2O_3	CaO	MgO	Na_2O	MnO	K_2O	LOI	C_3S	C_2S	C_3A	C_4AF
Soil	2.02	-	45.1	20.1	2.3	11.6	0.08	0.10	0.01	0.01	0.21	-	-	-	-	-
Cement	3.21	3200	19.8	7.1	-	3.6	56.2	1.2	0.38	-	0.69	0.06	51.1	23.1	5.1	8.4
RHA	1.95	3600	89.61	0.04	-	0.22	0.91	0.42	0.07	-	1.58	5.91	-	-	-	-

Table 3. Summary of optimum water content, maximum dry density, optimum cement content, and CBR value

Lateritic soil	Optimum water content (%)	Maximum dry density (t/m^3)	Optimum cement content (%)	CBR @ 95% OPM (%)
A	7.60	2.21	2.6	232
B	7.70	2.24	2.6	271
C	9.70	2.21	2.6	217
D	5.80	2,37	2.6	250
E	9.60	2,19	2.9	217
F	12.8	2.17	5.0	210
G	5.75	2.17	4.0	366

[a]((Table Footnote)); [b] …
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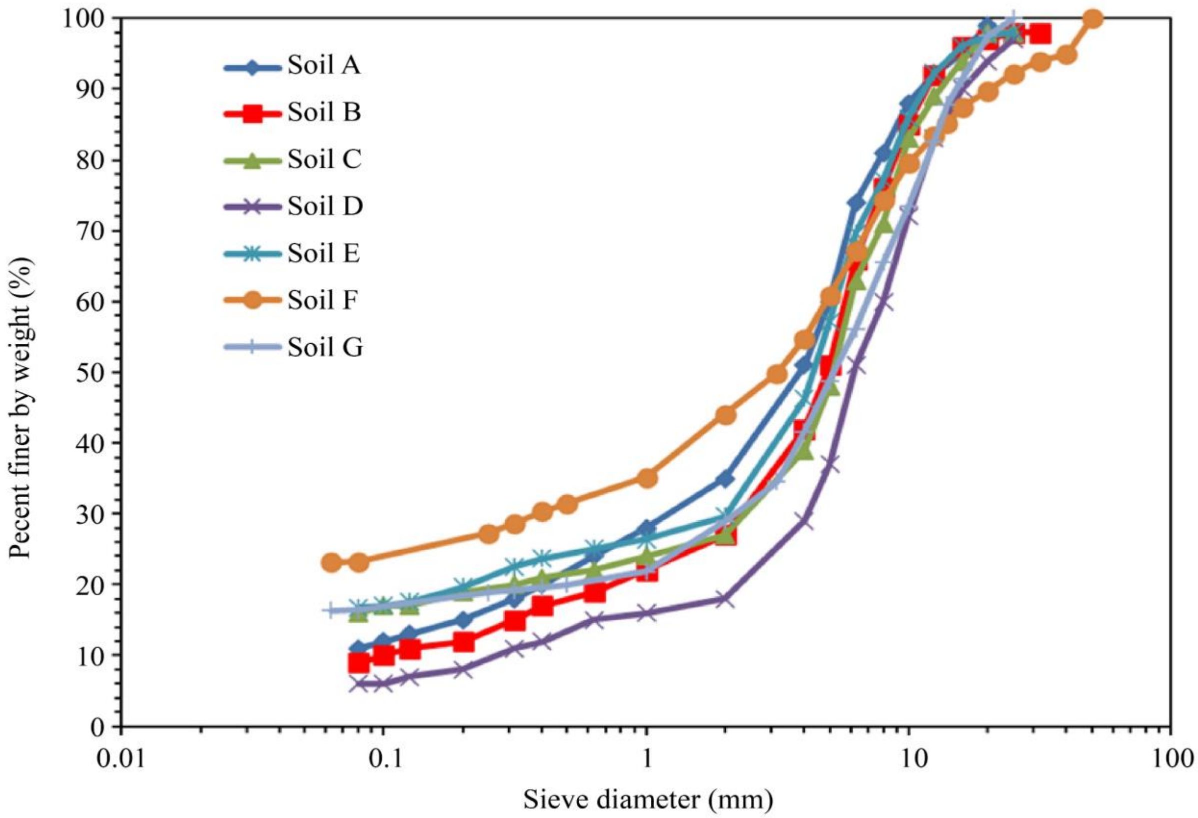

Fig. 2 Grain size distribution curve of laterite soils

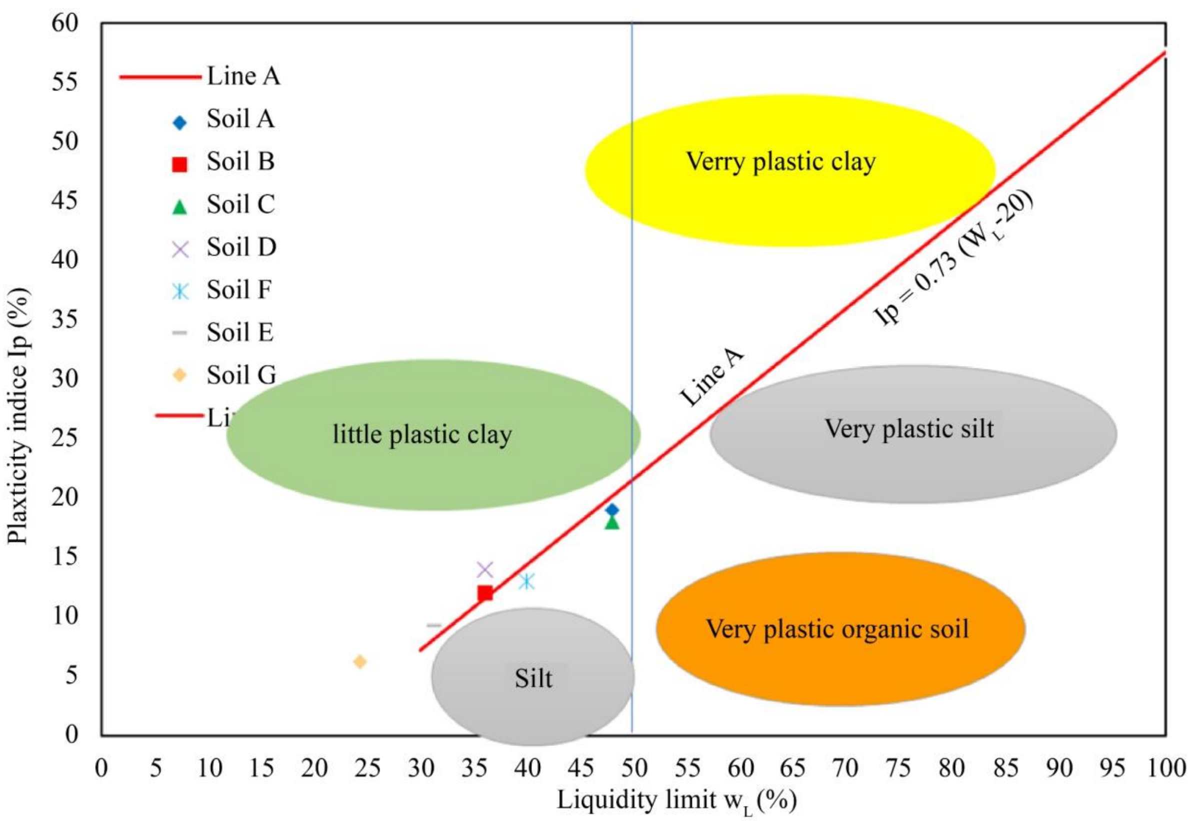

Fig. 3 Casagrande plasticity chart including laterite soils

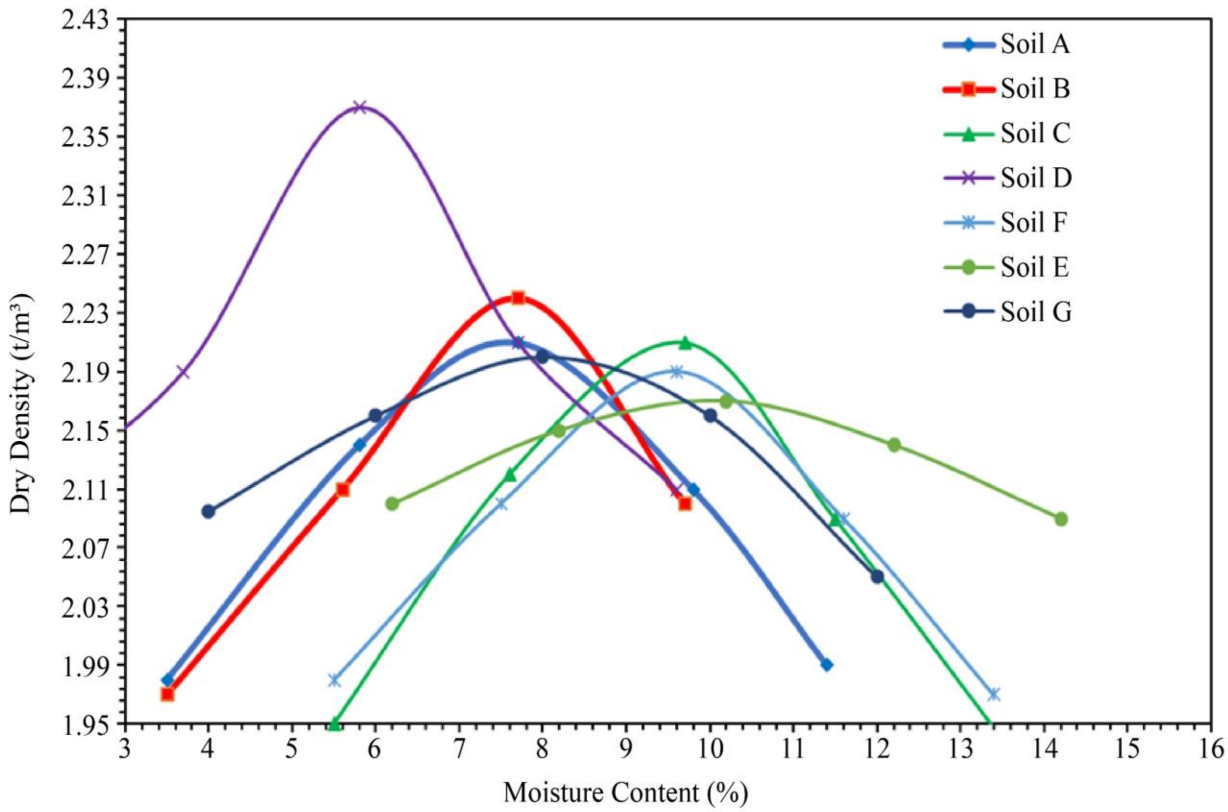

Fig. 4 Optimum Proctor for unstabilized laterite soils

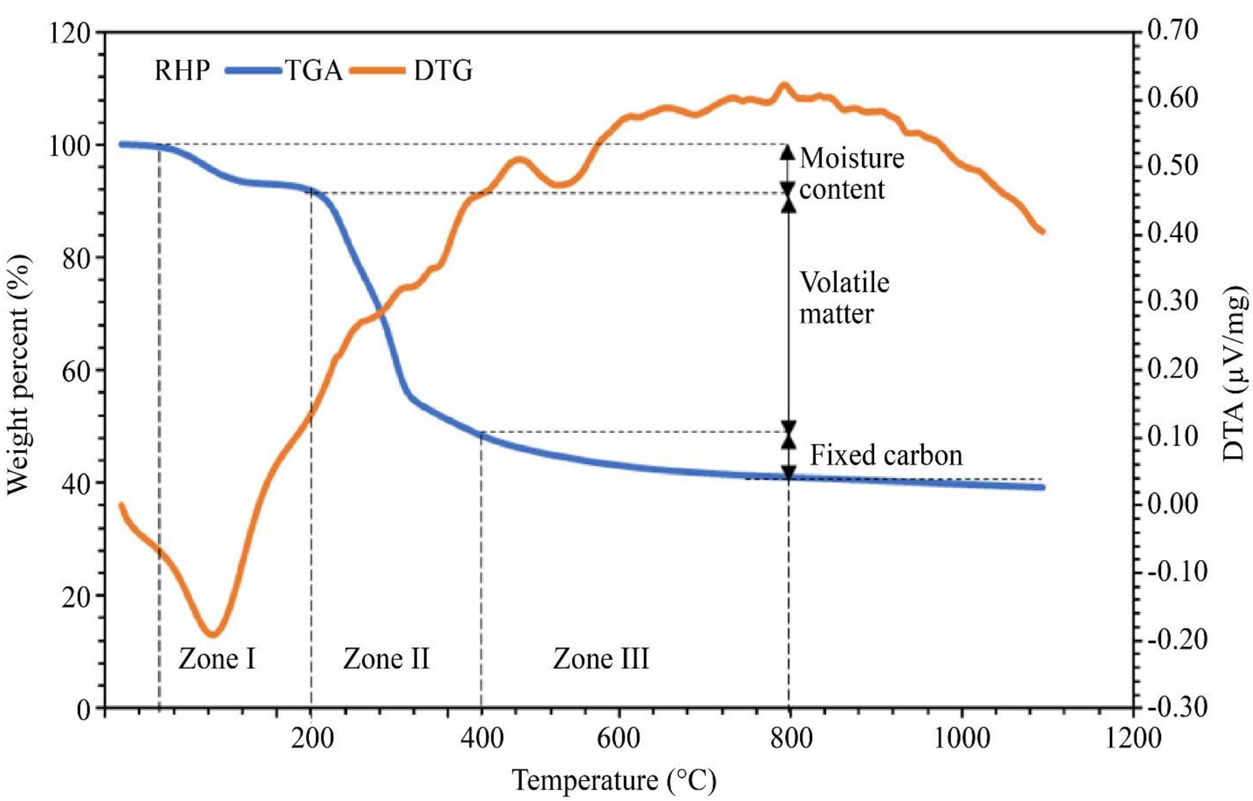

Fig. 5 Thermo-Gravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) curves for RHP

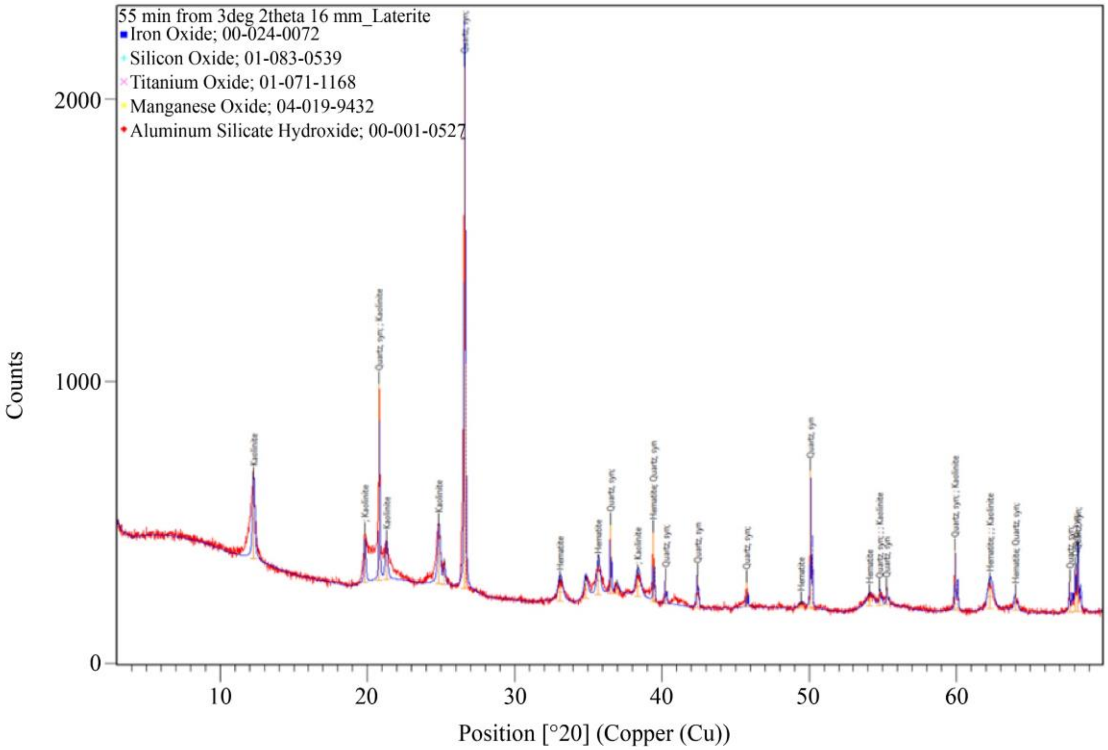

Fig. 6 X--Ray diffraction for laterite soil G

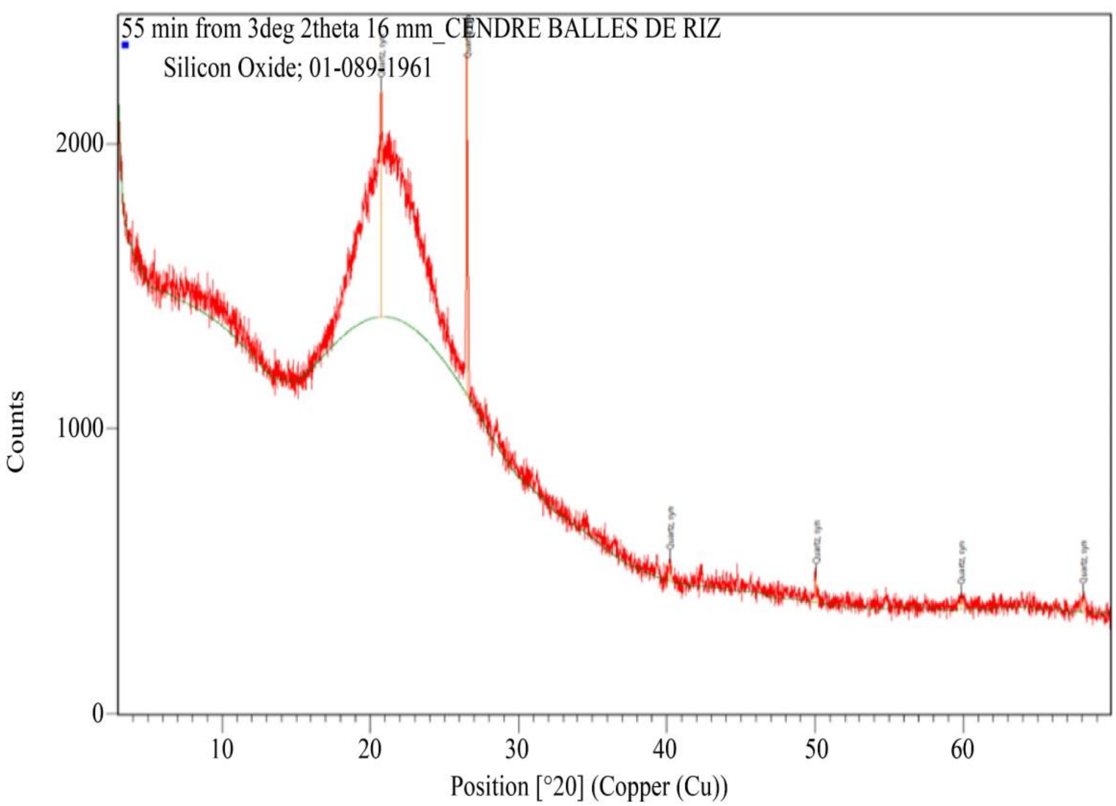

Fig. 7 X-ray diffraction for RHA

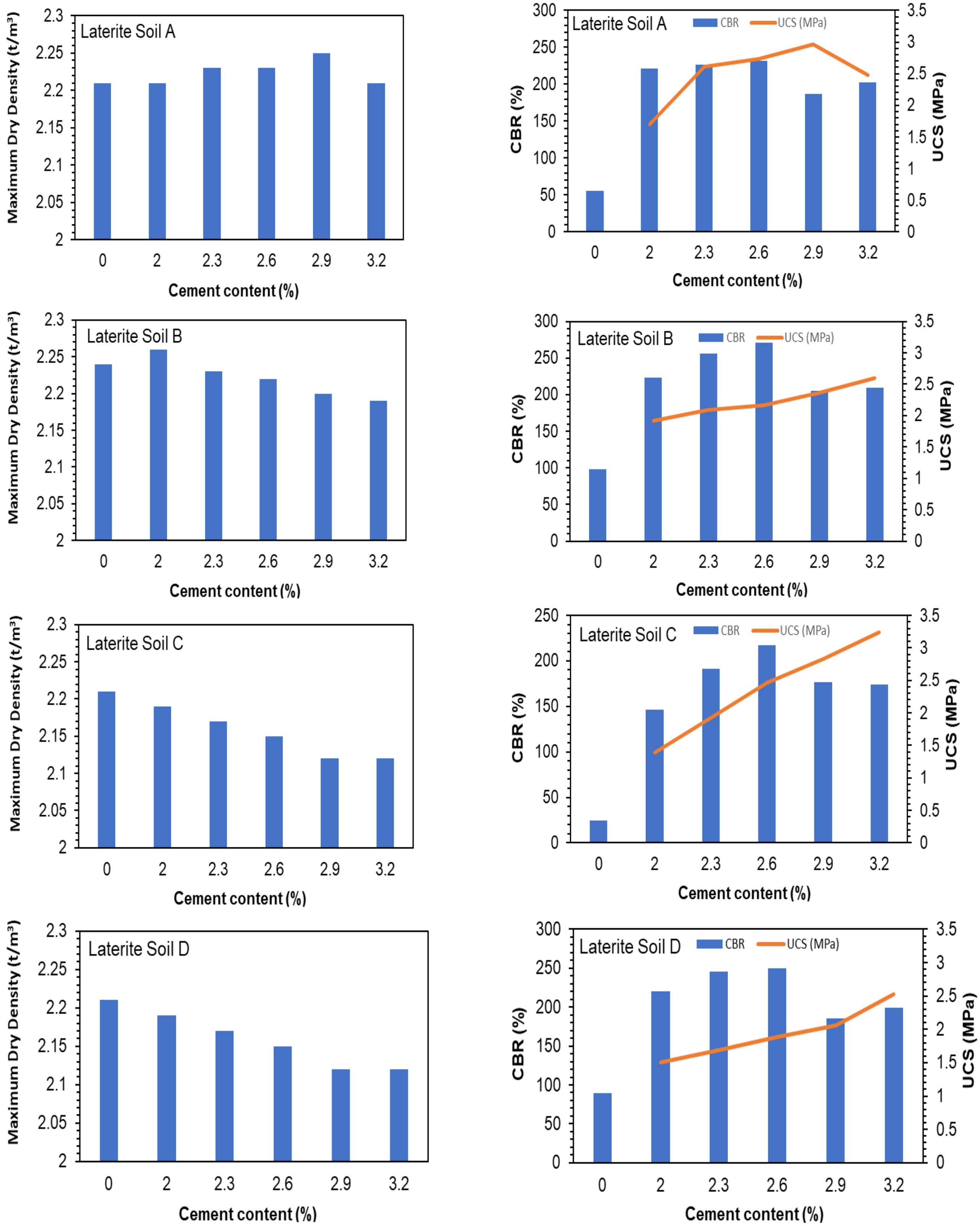

Fig. 8 Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS) depending on cement content of laterite soil A, B, C, and D

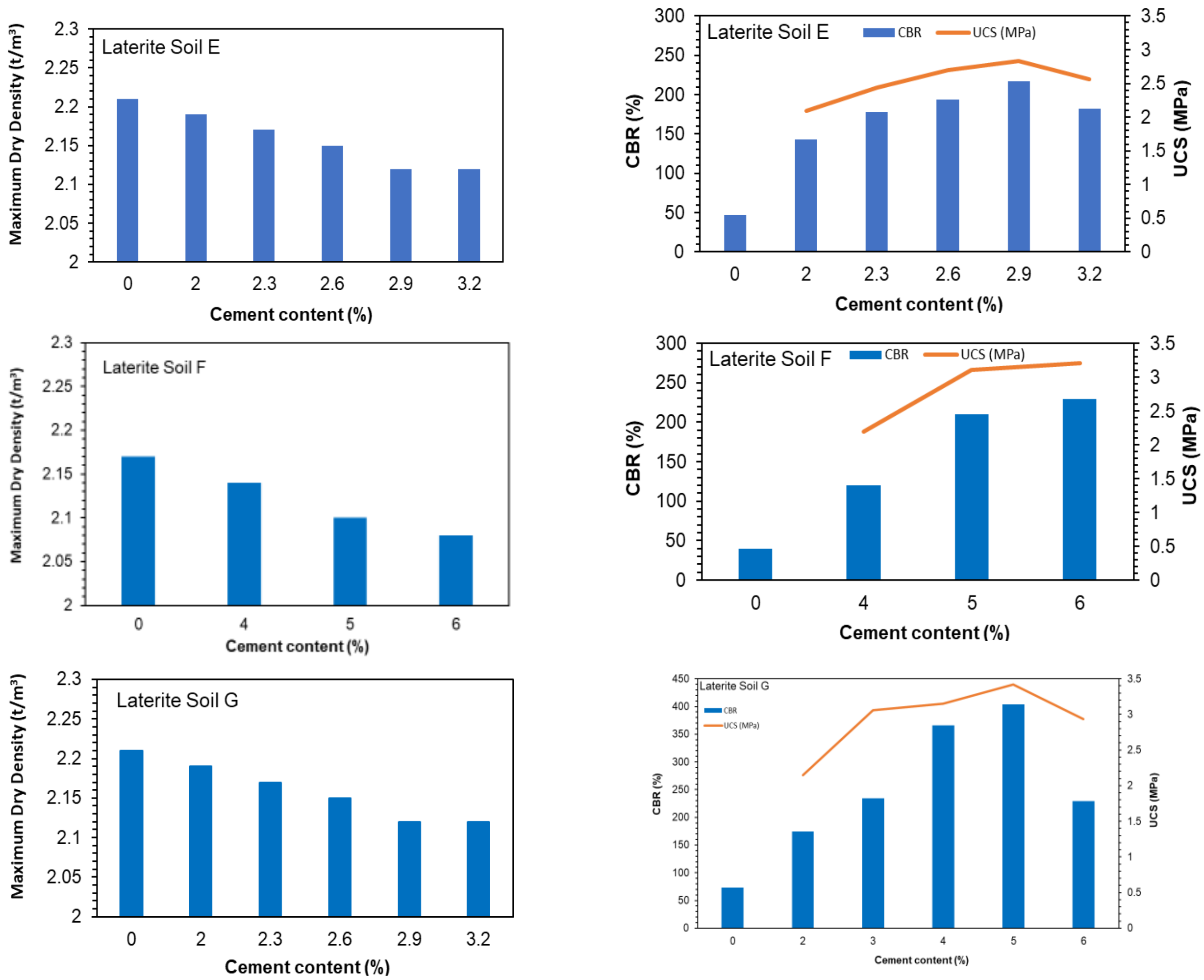

Fig. 9 Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS) depending on cement content of laterite soil E, F, and G

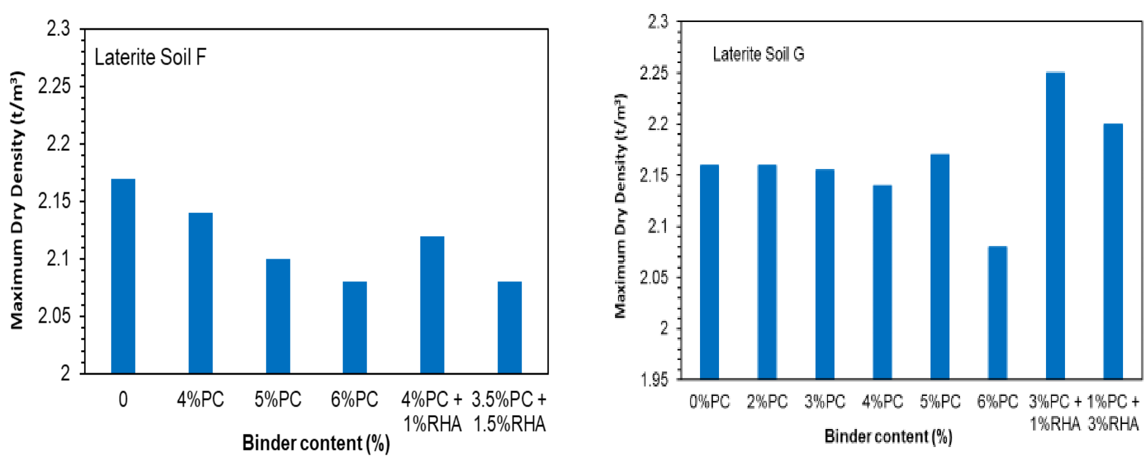

Fig. 10 Maximum dry density of stabilized laterite soil depending on binder content

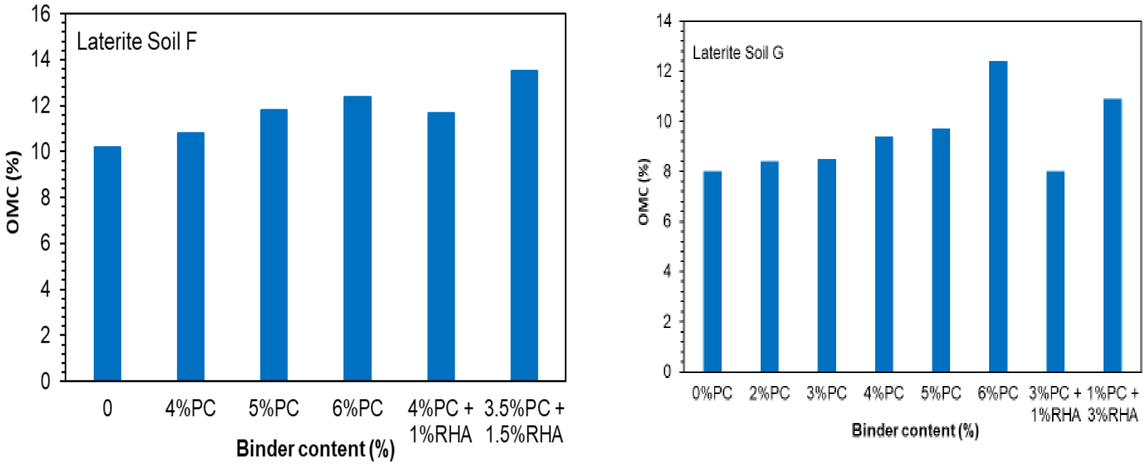

Fig. 11 Optimum moisture content of stabilized laterite soils depending on binder content

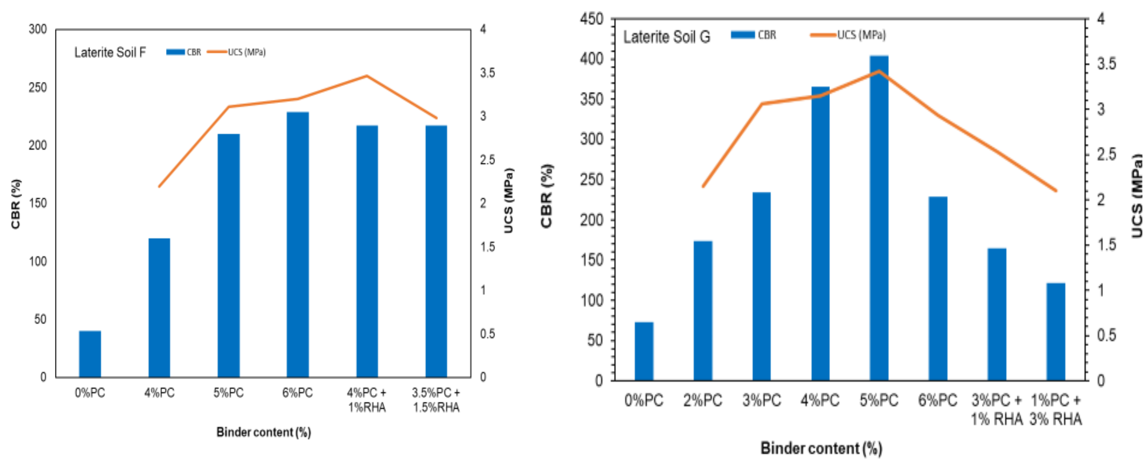

Fig. 12 CBR and UCS of ring Ratio and UCS of stabilized laterite soil depending on binder content

3.4. Mechanical Analysis on Raw Laterite Soil and Laterite Soil Stabilized with Cement

Laterite soil samples were stabilized with varying amounts of cement to improve soil physical and mechanical properties. The purpose of this stabilization is to determine the optimum cement content necessary to fulfil the requirements of the road design guideline [11] (MDD ≥ 2 t/m^3, CBR ≥ 160 and UCS 1.8 MPa-3MPa after 7 days curing) for base course. Figures 8 and 9 present the results of Maximum Dry Density (MDD), Californian Bearing Ratio (CBR) and Unconfined Compression Strength (UCS) for the laterite soil stabilized with cement @ 95% of Optimum Proctor Modified (OPM). Note that the punching ring of the CBR press was prone to failure for stabilized laterite soils A, B, D, with 2.9 and 3.2% cement content. Since the CBR was calculated at 2.5 and 5mm penetration, failure occurred for these soils before the displacement of 5 mm. Therefore, the CBR value at 2.5 mm penetration was considered in that case. In general, CBR increases with increasing cement content up to an optimum cement content, above which CBR decreases. In fact, the optimum process of the chemical reactions between laterite soil, cement and water in a well-defined proportion determines the soil-cement strength. Lower or higher cement content than this optimum cement content can impede the optimum reaction process and lead to strength reduction of the soil-cement, as shown in Figures 8 and 9.

On the other hand, soils A and B present a CBR peak at 2.6 and 2.9% cement content, respectively. This could be explained by the high percentage of fine particles, the high optimum water content, the mineralogical composition of these soils, and the reactions between the compounds of cement and clay particles in laterite soil (Table 2). When the tested laterite soils were stabilized with cement, all the soil-cement tested fulfilled the CBR requirements of CEBTP for treated materials (CBR ≥ 160), except laterite soils A and B, which fulfilled these CBR requirements, once they were stabilized with cement larger than 2%.

The UCS generally increases with increasing cement content. However, the UCS for the laterite soils A, E and F increases with increasing cement content up to a maximum resistance, then decreases slightly with further increasing of cement content.The mechanical characteristics (CBR and UCS) of stabilized soils increase with increasing cement content after 7 days of curing (Figures 8 and 9). This effect is primarily attributed to the pozzolanic reaction between laterite soil constituents (SiO_2, Al_2O_3) and cement (CaO), which over time leads to the formation of Calcium Silicate Hydrate (C–S–H) and Calcium Aluminate Hydrate (C–A–H). These reaction products act as binding agents, effectively cementing the soil particles together and enhancing the soil's mechanical strength. In stabilized soils, the Unconfined Compressive Strength (UCS) measured after 7 days of curing is a key parameter for evaluating the soil's suitability in accordance with road design guidelines [11]. On this basis, regarding the specification (UCS 1.8 MPa-3MPa after 7 days curing) of the road design guideline [11] for soil material to be used for road bases, the cement content by dry weight of each laterite soil given in Table 3 was established as the optimum cement content. Specifically, the optimum cement content is 5% and 4% for laterite soil F and G, respectively. For the valorisation of RHA and the reduction of greenhouse gases due to cement production, the optimum cement content for laterite soils F and G is gradually substituted by RHA for laterite soils F and G.

3.5. *Analysis of Laterite Soil Stabilized with Portland Cement (PC) and Rice Husk Ash (RHA)*

The laterite soils G and F were further stabilized by replacing cement with RHA. RHA replaced an increasingly cement content, starting from the optimum cement presented in section 0. The cement replacement is not increased up to 3%, over which a drastic decrease of strength parameters was found, Baimourne et al. (2023) [8]. The maximum dry density of stabilized laterite soil, depending on binder content, is shown in Figure 10. The maximum dry density decreased with increasing RHA content, which can be explained by the lower specific gravity of RHA (1.95 g/cm3) in comparison to that of cement (3.21 g/cm3) (see Table 2). However, the optimum moisture content of the sample stabilized with gradually replacing cement by RHA, increases with increasing RHA content (Figure 11). That can be attributed to finer particles in the mix matrix, since more volume of RHA is needed to replace the same weight of cement because it has a lower specific gravity. On the other hand, the specific surface of RHA (3600 cm2/g) is larger than that of cement (3200 cm2/g), so RHA needs more adsorbed water. The finer the material, the more water is needed to achieve maximum compaction, because of the lower specific surface. Figure 12 shows that soaked CBR and UCS continually decrease with cement content replacement by RHA after 7 days of curing. For the laterite soil F, the CBR remains approximately 217% for cement replacement by 1% and 1.5% RHA. However, the UCS of soil F decreases from 3.5 to 3.0 MPa for cement replacement with 1% and 1.5% RHA, respectively. Laterite soil G shows similar trends. When only a small fraction of cement is replaced by Rice Husk Ash (RHA) (e.g., 3 %), the reduction in strength parameters is minimal. However, this reduction becomes more pronounced with higher cement replacement levels. The observed decrease in soaked California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) is attributed to the excess RHA that does not participate in the pozzolanic reaction within the first seven days of curing. Owing to its lower specific gravity relative to cement and soil, the addition of excess RHA partially replaces soil in the mixture, resulting in a reduction of the overall mechanical performance of the stabilized material (Baimourne et al., 2023), Dabou et al. (2021) [10].

Both experiences and test results have shown that pozzolanic reactions continue beyond the initial 7-day curing period, leading to further improvements in the mechanical properties of the specimens. Nevertheless, the most critical parameters for assessing the suitability of cement-stabilized materials for road construction remain the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) measured after 7 days of curing [11]. Considering the strength parameter specifications (MDD $\geq$ 2 t/m3, CBR $\geq$ 160, UCS 1.5-3MPa for value after 7 days curing) of the road design guideline [11] for soil material to be used for pavement bases, the optimum mix of the additives is 3.5% cement +1.5% RHA and 3% cement +1% RHA for laterite soil F and G, respectively. The corresponding soaked CBR and UCS values are 217% and 3 MPa for laterite soil F, and 165% and 2.5 MPa for laterite soil G. Hence, RHA can partially replace cement for base course in pavement construction. These findings regarding the performance of RHA stabilized soils agree, in some instances, with the results reported by Domphoeun (2025) [18], Domphoeun (2024) [19], Mostafa (2024) [20], and Duong (2025) [21].

4. Conclusion

Seven laterite soils (A, B, C, D, E, F, G) in this study, consisting of clayey sand categorized from B3 to B6 in the NF EN ISO 17892-4 (EN ISO 17892-10: 2018) classification system, have been investigated. The chemical analysis shows that the main chemical compounds of the laterite soils are silicate oxide (quartz), aluminium oxide (alumina) and iron oxide (iron). According to X-ray diffraction, rice husk powder contains mainly silicate oxide (SiO_2) and was classed as a pozzolanic material.

Combined Thermogravimetry (TG) and Differential (DTG) analysis on rice husk powder revealed mass loss during the moisture release for a temperature range from 50°C to 240°C, followed by release of volatile matter from 240°C to 400°C. The release of fixed carbon was found to occur from 400°C to 800°C. Hence, the decarbonisation of rice husk powder for mobilizing the amorphous silica necessary for high mechanical performance is established to be 800°C. The results of the stabilization of laterite soil with cement show that both CBR and UCS increase with increasing cement content up to an optimum cement content, above which CBR and UCS decrease or slightly increase. However, the density of soil-cement mix generally decreases with increasing cement content due to the increasing amount of fine particles in the mix. With an increasing amount of fine particles in the mix, the specific surface of the mix increases, which requires larger water content for optimum compaction. The optimum cement content to reach the mechanical performance regarding CBR and UCS was determined to be 2.6, 2.6, 2.6, 2,6, 2.9, 5.0, 4.0% by weight of dry soil of A, B, C, D, E, F, G, respectively. The achieved values were UCS= 1.73 MPa and CBR=132% for soil A, UCS= 2.17 MPa and CBR=271% for soil B, UCS= 2.47 MPa and CBR=217% for soil C, UCS= 1.88 MPa and CBR=250% for soil D, UCS= 2.83 MPa and CBR=217% for soil E, UCS= 3.11 MPa and CBR=210% for soil F, UCS= 3.15 MPa and CBR=366% for soil G. The optimum cement-RHA mix proportion fulfilling the requirement of the road design guideline is 3.5% cement +0.5% RHA for laterite soil F and 3% cement +1% RHA for laterite soil G. The corresponding UCS and CBR value of the stabilized soil F at this proportion were 2.98 MPa and 217%, respectively. The corresponding UCS and CBR value of the stabilized soil G at this proportion were 2.53 MPa and 165%, respectively. Thus, it can be concluded that RHA is an ideal material to partially replace cement in the process of laterite soil stabilization for pavement construction purposes, for reducing greenhouse gases.

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Highlights

- Physical and chemical analyses have been performed on seven laterite soils and rice husk
- Laterite soils have been stabilized with Portland cement
- Partial replacement of cement by rice husk ash to fulfil requirements in the road design guideline
- The results demonstrated the feasibility of partially replacing cement with RHA in stabilizing laterite soils for use in road base construction in Benin

List of Symbols

RHP : Rice Husk Powder
RHA : Rice Husk Ash
CBR : California Bearing Ratio
UCS : Uniaxial or Unconfined Compressive Strength
MDD : Maximum Dry Density
OCC : Optimum Cement Content
GHG : Greenhouse Gas
CEBTP : Experimental Center for Research and Studies in Building and Public Works

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