Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 5 (2023) 1109

Journal of the Nigerian Society of Physical Sciences

Effect of Pre-Test Drying Temperature on the Properties of Lateritic Soils

L. O. Afolagboye[a,*], Z. O. Arije[a], A. O. Talabi[a], O. O. Owoyemi[b]

[a] *Department of Geology, Ekiti State University, Ado-Ekiti, Nigeria*
[b] *Department of Geology, Kwara State University, Malete, Nigeria*

Abstract

The properties of residual soils, according to literature, are sensitive to the pre-test drying method given to the sample prior to testing. Similarly, residual soils such as laterites/lateritic soils are formed under various climatic conditions; hence, they show different degrees of sensitivity to the pretest drying method. This work is therefore carried out to elucidate the influence of the pre-test drying temperature or method on the properties of three lateritic soils that developed over three different Pre-Cambrian basement complex rocks from Ado-Ekiti, SW, Nigeria. The soils were subjected to two pre-test drying temperatures before conducting laboratory tests. The pre-test drying temperatures considered in this study include air-drying, oven-drying at 60 °C, and oven-drying at 110 °C. Pre-test drying at 60° and 110 °C caused particle aggregation (which reduced the soil surface area) and loss of cohesion. Consequently, this reduced the specific gravity, optimum moisture content, clay content, consistency limits, and unconfined compressive strength of the lateritic soils. The maximum dry density and sand content increased as the pre-test drying temperature increased. The pre-test drying temperature did not significantly change the plasticity classification of the soils; however, at higher pre-test temperatures, the soils become less plastic. The free swell index of the lateritic soils increased with increasing pre-test drying temperatures (up to 60 °C) before decreasing when the temperature rose to 110 °C. This study has revealed the effect that pre-test drying temperatures may have on the properties of lateritic soils, and these may produce soil properties that do not likely indicate the actual field performance of the tested soils.

DOI:10.46481/jnsps.2023.1109

Keywords: Lateritic soil, Pre-test drying temperature, Index properties, Oven drying, Soil classification.

Article History :
Received: 05 October 2022
Received in revised form: 21 January 2023
Accepted for publication: 27 January 2023
Published: 04 February 2023

Communicated by: Oladiran Johnson Abimbola

---

1. Introduction

Lateritic soils/laterites are residual soils that are highly weathered. They are usually low in silica but have sufficient concentrations of iron and aluminum sesquioxide to have been cemented to some degree. Lateritic soils are restricted to tropical and subtropical regions of the world and occur as the capping of hills; therefore, they provide excellent borrowing areas for extensive use in various construction activities [1]. The properties and behavior of lateritic soils vary because of differences in degree of weathering (laterization), parent rock, climate, position in the soil profile, and topography [2, 3].

In civil engineering, the determination of soil index and engineering properties is important and integral to any engineering construction and design. To determine these

---

[*] Corresponding author tel. no: +2348037857241
Email address: `afotayour@hotmail.co.uk`; `lekan.afolagboye@eksu.edu.ng` (L. O. Afolagboye)

properties, tests such as consistency limits, grain size distribution, compaction, and strength tests are carried out using or on disturbed samples, and the test procedures completely re-mould the samples. That is, the samples must be carefully prepared to the required standards. For instance, one of the general specifications of sample preparation for most of these standard laboratory tests requires either air-drying or drying in an oven at a temperature usually between 60 °C to 110 °C. This is required to obtain fully dried soil, with the assumption that water present in the soil pore spaces could be removed by heating without destroying or changing the soil composition/structure. However, previous works have shown that this assumption may not be true for all soils [4, 5].

Previous workers such as [6, 7, 8] reported that the method of drying and generally the method of sample preparation may significantly affect the index properties of some soils such as weathered, tropical/subtropical residual soils or soils that contain organic matter and halloysite or allophane. Terzagi *et. al.* [9] reported the Atterberg limits and grain size distribution of residual soils from Indonesia tested at Natural Moisture Content (NMC) and when air dried and oven dried. When tested at NMC, the soil had Liquid Limit (W_L), Plasticity index (I_p) and amount of fine of 184%, 38%, and 95%, respectively. At NMC, the soil is classified as high plastic or organic silt. After air-drying, the amount of fines, W_L and I_p decreased to 19 %, 79 %, and 6 %, respectively. When oven-dried, the amount of fines was 15 % and the soil became "non-plastic". The soil classified as silty sand (SM) when air-dried and oven dried.

Hence, the index and engineering tests may yield inconsistent results or significantly different results as they are influenced by the degree of pre-test drying temperature (NMC, oven-dried or air-dried) used prior to testing. These changes are attributed to increased cementation due to oxidation of the iron and aluminum sesquioxides or dehydration of allophane and halloysite [10]. In addition, pre-test drying may alter the structure, physical behavior, and clay content of a residual soil by causing aggregation of fine particles. The resultant larger particles remain bonded together even on wetting or after dispersion by standard dispersion techniques [5, 11]. Previous studies have shown that lateritic soils are structured and contain significant concentration of iron and aluminum sesquioxides hence their properties are likely to be affected by the pre-test method of drying and generally the method of sample preparation [6, 7, 8]. In addition, the sensitivity of different lateritic soils to pre-test drying, and sample manipulation is different depending on climatic conditions [12].

The present study is therefore aimed at further understanding the properties/behavior of the residual lateritic soil whose behaviors are termed problematic by investigating the effect of pre-test drying temperature on the geotechnical and index properties of lateritic soils. These problematic behaviors can't be explained by the accepted principles established for temperate soils [13]. In addition, to provide further insights as to why the plasticity classifications of the soil are sometimes not in agreement with the major component of the soil and in situ observations. Three different genetically derived lateritic soils were selected for this study.

2. Geology of the Study Area

Ado-Ekiti is one of the areas of southwestern Nigeria underlain by the Pre-Cambrian basement complex rocks. The rocks of the Pre-Cambrian basement complex are classified as "migmatite gneiss-quartzite complex," "Schist Belts", and "Pan-African Granites" [14]. Except for the schistose rocks, Ado-Ekiti contains most of the rock lithologies that comprise the Precambrian basement complex of southwestern Nigeria [15]. These rocks include charnockite, migmatite gneiss, granite, and granite gneiss. Migmatite gneiss is characterized by a fine-grained texture and alternating bands of dark and light-colored minerals. Quartzites are ridge-shaped, non-foliated rocks. With only a trace amount of feldspar, quartz makes up the majority of the quartzite's mineral composition. The constituent minerals in the granites do not exhibit any preferred orientation. They range from having a fine-grained to porphyritic texture. The granites also contain compact crystals that interlock with one another. Charnockite has a dark gray color and a texture that ranges from medium to coarse. Charnockite can be found along the edges of granites [16, 17].

3. Methodology

The lateritic soils used in this study developed over three different rock types. These rocks are granite, charnockite, and quartzite. The granite is made of quartz (66.3 %), biotite (12.2 %), albite (20.3 %), and opaque minerals [16]. Quartzite is mainly made up of quartz (about 95.1 %) and other minerals such as feldspar. The charnockite, on the other hand, is made up of quartz (21.3 %), microcline (16.7 %), plagioclase (36.8 %), biotite (16.5 %) and others [17]. Disturbed lateritic soil samples (that developed over quartzite and granite) were collected from active burrow pits where lateritic soil is presently being quarried for different construction purposes in Ado-Ekiti, Southwestern, Nigeria while samples of lateritic soil that developed over charnockite were collected from a road cut exposure. The samples were collected from the laterite horizon because lateritic soil from this zone is the most preferred for most construction activities [3], [18]. The collected samples were stored in airtight sealed polythene bags to keep their water contents intact. In all, a total of five soil samples were taken from soils that developed over the three rock types. The lateritic soil samples were tested at their Natural Moisture Content (NMC) and three other states obtained through drying. These include air-dried soil, and soils oven dried at 60 °C and 110 °C.

3.1. Drying Process

The soil samples that were not tested at their NMC were prepared under the following drying conditions:

i. Air Drying: the soil samples were spread on a clean wide pan and the spread samples were exposed to normal ambient temperature (25 to 30 °C) for three — four weeks. During this period, we regularly turned the soil over to avoid local drying out. It is sufficing to say that it takes at least four weeks to reduce the moisture content of the air-dried samples to a relatively constant value.
ii. Oven drying at 110 °C: This entails drying the soil samples to a constant mass in an oven at a temperature of 110 ± 5 °C as stipulated by [19]. The period of heating is 24hrs.
iii. Oven drying at 60 °C: This entails drying the soil samples to a constant mass in an oven at a temperature of 60 ± 5 °C. During heating, we constantly measured the weight of the samples and stopped the heating process when the weight of the samples became constant.

3.2. Index and Engineering Tests Procedure

The index and engineering properties of these genetically different lateritic soil samples at their natural moisture content, air dried, and oven dried (60 °C and 110 °C oven drying) states were determined according to British Standard 1377 [19] with some modifications where necessary. The particle size analysis was carried out using British Standard 1377-2. To ensure proper segregation of the soil particles, we soaked the soil samples in Calgon solution for a day before wet sieving. We conducted the particle size analysis using sieve analyses and hydrometer test. Soil fractions retained on and passed through sieve No. 200 (75 μm), respectively, were used for sieve analyses and hydrometer test. The consistency limits were also determined using British Standard 1377-2 on soil fraction passing sieve size 425 μm. The determined consistency limits of the soils include liquid limits and plastic limits. Before the consistency limits tests, the sieved soil fractions were mixed with water and left to hydrate for 24 hrs. We determined the $\mathrm{W_L}$ and Plastic Limit ($\mathrm{W_P}$) of the soils using the Casagrande percussion cup and thread rolling methods, respectively.

For determining the moisture-density relationship of the soil samples, compaction test was carried out on fractions of the soils that passed through 425 μm sieve following the specification of British Standard 1377 – 4. We carried out the compaction test using the standard Proctor compaction efforts. The specimens for the moisture — density relationship test is about 10.2 cm and 11.2 cm in diameter and height, respectively. We performed the Unconfined Compression Test (UCT) on lateritic soil following the specification of British Standard 1377 – 7. The specimens were compacted at their Optimum Moisture Content (OMC) using the standard Proctor compaction effort. The specimens used for the test measured 5 cm and 10 cm in diameter and height, respectively. The compacted soil sample were loaded under a stress-strain controlled condition. The strain rate was set at 1.25 mm/min. We compressed the soil specimen till failure and monitored the deformation at each point of loading. The peak stress attained during loading correspond to the unconfined compressive strength.

Free swell index (FSI) was carried out on fractions of lateritic soil that pass-through sieve size 0.425 mm. According to Rao *et. al.* [20], FSI can be considered as an index property of expansive soil, and it reflects the potential for expansion of the soil. Holtz and Gibbs [21] defined the FSI as the ratio of the difference in volumes of soil in water and kerosene to the volume of soil in kerosene. It is mathematically expressed as:

$$FSI = \frac{V_d - V_k}{V_d} \times 100, \tag{1}$$

where $\mathrm{V_d}$ (ml) = final volume of soil in a graduated cylinder containing distilled water, $\mathrm{V_k}$ (ml) = final volume of soil in a graduated cylinder containing kerosene. Therefore, FSI is expressed in (%).

4. Results and Discussion

SG is an indicator for engineering behavior of lateritic soils in that, it's the weighted average of the specific gravities of the minerals which comprise the soil. However, weathering and age of formation of parent rocks are fact factors to be considered while determining SG. Table 1 shows the specific gravity of the studied lateritic soils for all pre-test drying methods. At NMC, the table revealed that the average SG values of quartzite derived lateritic soil, charnockite derived lateritic soil and granite derived lateritic soil are 2.648, 2.686 and 2.670, respectively. The difference between the SG of the three lateritic soils may be due to the variation in texture and mineralogy of the parent rocks.

Compared with lateritic soil tested at NMC, the SG of the three genetically different lateritic soils were lower and decreased as the drying temperature increases from air to oven drying at 110 °C. The difference is, however, not significant. Sunil and Krishnappa [22] studied "the influence of drying on the properties of lateritic soils and observed that the SG of the air and oven dried lateritic soils did not vary significantly from each other. At NMC and all the pretest drying temperatures, the average SG of charnockite-derived lateritic soil is higher compared to the other lateritic soils. This could be attributed to the mineral constituent of the parent rock which contained more heavy and opaque minerals compared to granite and quartzite [16]. Generally, the high SG values of the soils are indicative of a high degree of laterization.

4.1. Particle Size Distribution

Table 2 shows the results of particle size distribution of the lateritic soils as determined at their NMC, after air drying and oven-drying at 60 °C and 110 °C, respectively. The table reveals that the grain size distribution of the lateritic soils is affected by the parent rock factor.

At NMC and all pre-test drying temperature, the lateritic soils are well-graded. The amount of sand size fractions in the lateritic soils are high. Quartzite derived-lateritic soils

Table 1: Effect of Pre-Test Drying Temperature on the Specific Gravity of the Lateritic Soil

Parent Rock	Drying Method	SG			Average		
Quartzite	NMC	2.642	2.648	2.645	2.652	2.653	2.648
	Air dried	2.643	2.644	2.643	2.643	2.643	2.643
	Oven Dried at 60 °C	2.642	2.642	2.645	2.641	2.641	2.642
	Oven Dried at 110 °C	2.634	2.634	2.636	2.636	2.631	2.634
Charnockite	NMC	2.687	2.688	2.685	2.685	2.686	2.686
	Air dried	2.688	2.687	2.685	2.686	2.684	2.686
	Oven Dried at 60 °C	2.675	2.677	2.675	2.676	2.676	2.676
	Oven Dried at 110 °C	2.661	2.661	2.664	2.665	2.663	2.663
Granite	NMC	2.668	2.674	2.672	2.668	2.666	2.670
	Air dried	2.667	2.668	2.67	2.662	2.664	2.666
	Oven Dried at 60 °C	2.664	2.665	2.661	2.659	2.663	2.662
	Oven Dried at 110 °C	2.654	2.655	2.654	2.655	2.653	2.654

Table 2: Grain Size Distribution of the Lateritic Soils at Different Pre-Drying Temperature

Parent Rock	NMC				Air dried				Oven Dried at 60 °C				Oven Dried at 110 °C			
	G (%)	S (%)	Si (%)	C (%)	G (%)	S (%)	Si (%)	C (%)	G (%)	S (%)	Si (%)	C (%)	G (%)	S (%)	Si (%)	C (%)
Quartzite	1.3	55.0	19.8	23.9	1.2	56.5	18.5	23.8	1.2	58.6	19.5	20.7	1.1	60.8	19.6	18.5
	0.9	54.2	20.0	24.9	0.7	57.5	16.3	25.5	1.1	58.9	19.3	20.7	1.0	60.7	18.7	19.6
	0.7	56.0	18.5	24.8	0.6	57.1	17.5	24.8	0.9	58.9	18.3	21.9	0.8	61.4	18.3	19.5
	1.0	54.9	20.4	23.7	0.9	57.2	17.3	24.6	1.5	58.4	19.0	21.1	1.5	61.0	18.4	19.1
	1.0	54.0	19.8	25.2	1.3	57.0	14.9	26.8	1.2	58.7	19.1	21.0	1.1	61.0	18.8	19.1
Average	1.0	54.8	19.7	24.5	0.9	57.1	16.9	25.1	1.2	58.7	19.0	21.1	1.1	61.0	18.8	19.2
Charnockite	0.7	46.7	20.7	31.9	0.6	49.2	20.4	29.8	0.6	51.0	20.7	27.7	0.6	53.3	20.5	25.6
	0.9	46.1	20.0	33.0	0.8	48.9	19.7	30.6	0.8	50.8	19.9	28.5	0.8	53.2	19.6	26.4
	0.5	46.0	20.4	33.1	0.4	49.0	19.7	30.9	0.4	51.1	20.5	28.0	1.1	52.6	20.3	26.0
	0.5	45.0	21.8	32.7	0.5	48.8	22.4	28.3	0.5	51.3	21.0	27.2	1.2	52.4	20.9	25.5
	0.6	45.0	21.0	33.4	0.8	48.2	21.6	29.4	0.6	51.0	20.6	27.8	0.9	52.9	20.4	25.8
Average	0.6	45.8	20.8	32.8	0.6	48.8	20.8	29.8	0.6	51.0	20.5	27.8	0.9	52.9	20.3	25.9
Granite	1.4	48.3	20.8	29.5	0.9	50.4	21.4	27.3	0.9	52.0	18.8	28.3	0.8	54.2	18.7	26.3
	0.9	48.4	18.5	32.2	1.0	50.1	19.2	29.7	1.0	51.8	17.9	29.3	0.9	53.7	18.1	27.3
	0.7	49.0	18.6	31.7	0.6	50.0	19.1	30.3	1.3	51.4	18.2	29.1	1.2	53.6	18.1	27.1
	1.0	48.5	19.5	31.0	0.9	50.4	20.4	28.3	1.4	51.2	19.1	28.3	1.3	53.4	19.0	26.3
	1.0	48.6	19.3	31.1	0.9	49.6	19.8	29.7	1.2	51.6	18.5	28.7	1.1	53.8	18.5	26.6
Average	1.0	48.6	19.3	31.1	0.9	50.1	20.0	29.1	1.2	51.6	18.5	28.7	1.1	53.7	18.5	26.7

NMC, Natural Moisture Content; G, Gravel; S, Sand; Si, Silt; C, Clay

have more than 50% sand content at all the pre-test drying temperatures. From Table 2, it could be observed that the amount of clay and sand fractions are affected by method of drying that is the pre-test drying temperature. The percentage sand and clay fractions of the lateritic soils increased and reduced, respectively, with an increase in pre-test drying temperature. For instance, the average clay size fractions decreased from 24.5 to 19.2 %, 32.8 to 25.9 % and 31.1 to 26.7 % in quartzite, charnockite and granite derived lateritic soils respectively. Furthermore, it was also observed that the decrease and increase, respectively, in percentage clay and sand contents was mostly influenced by oven-drying at 110 °C than oven-drying at 60 °C and air drying when compared with NMC. The average percent increase in sand content for lateritic soil derived from quartzite was 4.2 %, 7.12 %, and 11.31 % at drying temperatures of air-drying, 60 °C, and 110 °C, respectively. The average percent reduction in clay content for soil derived from charnockite was 9.15 %, 15.24 %, and 21.04 % at pre-test drying temperatures of air-drying, 60 °C, and 110 °C, respectively. Basma et al. [6] made similar observation while studying the influence of drying methods on the properties of clays. The silt fractions of the soils, however, remain virtually constant at all the pre-test drying temperature.

The decrease and increase in clay and sand fractions, respectively, of the lateritic soils may be attributed to particle aggregation as a result of drying (that is increase in temperature of pre-test drying). According to previous work, drying promotes loss of adsorbed and inter-particle water [23]. This mechanism leads to aggregation of smaller fine particles, inter-particle attraction and separation of small particles [6]. This eventually produce an increase in capillary stress which allows close contact of particles in addition to development of strong Coulombic and Van der Waal bonds which are not easily reversible [5].

4.2. Consistency Limits

Table 3 shows the results of consistency limits of the lateritic soils as determined at their NMC, by air drying and oven-drying at 60 °C and 110 °C. The W_L and I_P of charnockite-derived lateritic soil were constantly higher than lateritic soils derived from granite and quartzite at all the pre-test drying temperatures used in this study. The W_L and I_P of the lateritic soils reduced with increase in pre-test drying temperature (Table 3). The significance of this effect is that NMC samples gave the highest W_L and I_P values while samples oven-dried at 110 °C gave the lowest values. In quartzite-, charnockite- and granite-derived lateritic soils, the averages I_P decreased from 41.9 %, 56.7 % and 52.6 % when the samples were tested at their NMC to 37.6 %, 50.5 % and 48.0 % when the samples were tested after oven-dried at 110 °C, respectively. Increase in pre-test drying temperature, according to Sunil and Deepa [24], leads to aggregation and clustering of soil particles. The agglomeration of particles reduces the soils available surface area available for water interaction. This in turn will make the soil to absorb less water and consequently reduces the W_L and I_P. The results of particle size distribution also confirmed this observation. As earlier reported, the amount of clay and sand fractions in the lateritic soils are affected by the pre-test drying temperature. The percent clay and sand contents, respectively, decreased and increased as the pre-test drying temperature increases.

Similar to the grain size distribution, it was also observed that the decrease in W_L and I_P for the three tested lateritic soils was mostly influenced by oven-drying at 110 °C more than oven-drying at 60 °C and air drying when compared with NMC. In charnockite-derived lateritic soil, the results in this research show a reduction in the I_P when oven dried at 110 °C giving the highest reduction of 11.37 % while oven-dried at 60 °C and air-dried samples gave 8.57 % and 6.41 % reduction from NMC value. In granite-derived lateritic soil, a reduction of 6.16 % (oven-dried at 110 °C), 1.38 % (oven dried at 60 °C), and 0.22 % (air dried). The sensitivity of a soil, as revealed in the literature, to pre-test drying depends on the type of clay mineral present and its state of hydration[6, 25]. It has been revealed that soils containing kaolinite are less sensitive to pre-test drying [25].

4.3. Plasticity Charts

The decrease in consistency limits because of increase in pre-test drying temperature may become a significant factor as this may change the classification of the soil. To examine the effect of pretest drying temperature on the plasticity classification of the lateritic soils, the values of W_L and I_P in Table 3 were used to plot the points on Casagrande and Polidori [26] plasticity charts (Figures 1 and 2). It was observed that Polidori's plasticity chart gives a fair classification of lateritic soils based on soil fractions [27].

On the Casagrande's plasticity chart (Figure 1), the soils all plotted in the clay zones i.e., above the A-line. The soils are classified as either CI or CH. It was observed that even

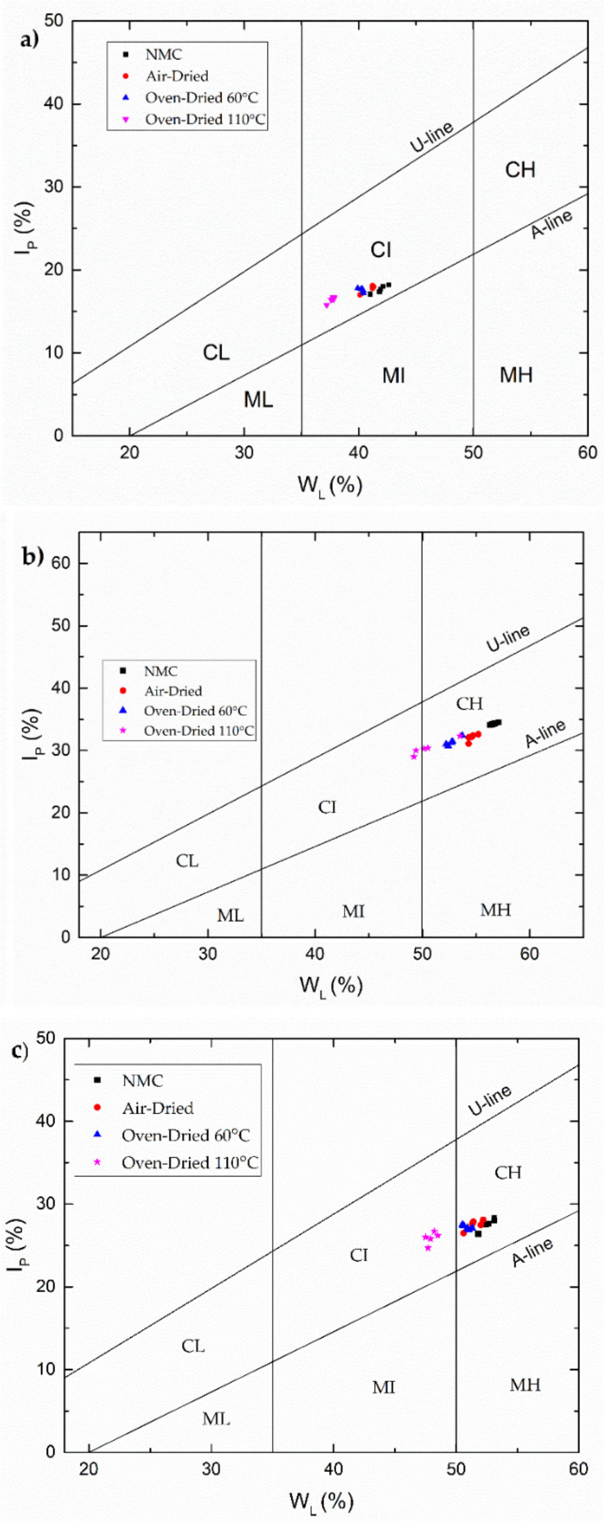

Figure 1: Casagrande Plasticity Classification of the lateritic Soil. a) Quartzite-derived lateritic soil b) Charnockite-derived lateritic soil c) Granite-derived lateritic soil. CL: Inorganic clays of low plasticity; CI: Inorganic clays of intermediate plasticity, CH: Inorganic clays of high plasticity; ML: Inorganic silts of low compressibility; MI: Inorganic clays of intermediate plasticity; MH: Inorganic silts of high compressibility

Table 3: Consistency Limits of NMC, Air Dried, and Oven Dried Lateritic Samples.

Parent Rock	NMC			Air dried			Oven Dried at 60 °C			Oven Dried at 110 °C		
	W_L (%)	W_P (%)	I_P (%)	W_L (%)	W_P (%)	I_P (%)	W_L (%)	W_P (%)	I_P (%)	W_L (%)	W_P (%)	I_P (%)
Quartzite	42.60	24.40	18.20	41.30	23.30	18.00	40.40	22.90	17.50	37.80	21.20	16.60
	41.80	24.40	17.40	40.30	23.10	17.20	40.20	22.50	17.70	37.80	21.10	16.70
	42.10	24.10	18.00	41.20	23.40	17.80	40.30	22.60	17.70	37.80	21.30	16.50
	41.00	23.90	17.10	40.10	23.10	17.00	39.90	22.10	18.00	37.20	21.40	15.80
	41.90	24.20	17.70	41.20	23.10	18.10	40.40	23.20	17.20	37.60	21.20	16.40
Average	41.88	24.20	17.68	40.82	23.20	17.62	40.24	22.66	17.58	37.64	21.24	16.41
Charnockite	56.30	22.20	34.10	54.30	22.20	32.10	52.70	21.40	31.30	53.50	21.20	32.30
	57.10	22.60	34.50	55.20	22.60	32.60	53.70	21.30	32.40	50.10	19.80	30.30
	56.80	22.40	34.40	54.60	22.40	32.20	52.40	21.70	30.70	49.40	19.40	30.00
	56.50	22.30	34.20	54.70	22.30	32.40	52.20	21.20	31.00	49.20	20.20	29.00
	56.70	22.40	34.30	54.30	23.20	31.10	52.80	21.40	31.40	50.50	20.10	30.40
Average	56.68	22.38	34.30	54.62	22.54	32.10	52.76	21.40	31.36	50.54	20.14	30.40
Granite	53.10	25.10	28.00	52.20	24.10	28.10	51.30	24.20	27.10	48.50	22.30	26.20
	52.40	24.90	27.50	51.40	23.50	27.90	51.00	24.10	26.90	48.20	21.50	26.70
	51.80	25.40	26.40	50.60	24.10	26.50	50.60	23.20	27.40	47.50	21.50	26.00
	53.10	24.70	28.40	52.00	24.50	27.50	50.50	23.00	27.50	47.70	23.00	24.70
	52.60	25.00	27.60	51.30	23.70	27.60	50.90	23.80	27.10	47.90	22.10	25.80
Average	52.60	25.02	27.58	51.50	23.98	27.52	50.86	23.66	27.20	47.96	22.08	25.88

NMC, Natural Moisture Content; W_L, Liquid Limit; W_P, Plastic Limit; I_p, Plasticity Index

though the silt and sand fractions (combined) of the lateritic soils were more than the clay fractions, the lateritic soils are classified as CH or CI soils. The pre-test drying temperature does not change the classification of the quartzite-derived lateritic soil (Figure 1a) and charnockite-derived lateritic soil; except for two samples oven-dried at 110 °C. The classification of these samples changed from CH to CI (Figure 1b). In samples where the classification does not change, a closer look at relative shift in position of the points on the Casagrande's chart distinctly shows that lateritic soils are becoming less plastic as the pre-test drying temperature increases. In granite derived lateritic soils, the pre-test dying temperature change the classification of the soil oven dried at 110 °C (Figure 1c).

On the Polidori's plasticity chart (Figure 2), the soils plot above the C-line (silt zones). The soils are classified as either ML or MH. The pre-test drying temperature does not change the classification of the quartzite-derived lateritic soil (Figure 2a) and charnockite-derived lateritic soil; except for two samples oven-dried at 110 °C. The classification of these samples changed from MH to ML (Figure 2b). In granite-derived lateritic soils, the pre-test drying temperatures change the classification of the soil oven dried at 110 °C (Figure 2c).

4.4. Compaction Parameters

The moisture content-dry density relationships of the lateritic soils were obtained at their NMC, air-dried and oven-dried (60 ° and 110 °C) conditions. Table 4 shows the results of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the lateritic soils. The MDD of charnockite derived lateritic soil were constantly higher than lateritic soils derived from granite and quartzite at all the pre-test drying temperatures.

The MDD and OMC increased and reduced, respectively, with increase in pre-test drying temperature (Table 4). The soil samples tested at their NMC gave the lowest MDD (highest OMC) values while samples oven-dried at 110 °C gave the highest MDD (lowest OMC) values. In quartzite-, charnockite- and granite-derived lateritic soils, the average MDD increased from 1787 kg/m^3 1858 kg/m^3 and 1703 kg/m^3 when the samples were compacted at their NMC to 1926 kg/m^3, 1954 kg/m^3 and 1857 kg/m^3 when the samples were compacted after oven-dried at 110 °C, respectively. On the other hand, the average OMC of quartzite, charnockite and granite derived lateritic soils, respectively, decreased from 21.88 %, 21.68 % and 24.63 % (NMC) to 17.33 %, 18.2 % and 19.56 % when oven-dried at 110 °C. These results agree with the findings of previous researchers [11, 24]. The changes in the compaction parameters of the lateritic soils as a result of pre-test drying temperature may be attributed to the effect of particle aggregation and re-

Table 4: Compaction Parameters of the Lateritic Soils

Parent Rock	NMC		Air dried		Oven Dried at 60 °C		Oven Dried at 110 °C	
	OMC (%)	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)
Quartzite	22.40	1772	21.50	1797	19.00	1874	16.90	1940
	21.60	1794	20.80	1819	19.30	1865	17.40	1924
	22.10	1781	20.50	1828	19.50	1859	17.70	1915
	21.40	1800	20.90	1815	19.20	1867	17.30	1928
	21.90	1788	20.95	1811	19.30	1865	17.30	1923
Average	21.88	1787	20.93	1814	19.26	1866	17.33	1926
Charnockite	21.80	1856	21.20	1870	20.00	1904	18.40	1948
	21.40	1864	20.80	1881	19.70	1912	18.20	1954
	21.60	1859	20.40	1892	19.90	1906	18.00	1960
	21.90	1853	20.80	1880	19.90	1910	18.20	1950
	21.70	1857	20.80	1882	19.80	1903	18.10	1958
Average	21.68	1858	20.80	1881	19.86	1907	18.20	1954
Granite	24.60	1704	24.10	1719	22.80	1760	20.00	1843
	24.40	1710	23.70	1732	22.30	1775	19.40	1862
	25.00	1692	23.80	1729	23.00	1754	19.30	1865
	24.50	1707	23.90	1723	22.70	1764	19.60	1857
	24.60	1702	23.90	1728	22.80	1762	19.50	1858
Average	24.63	1703	23.87	1727	22.70	1763	19.56	1857

duction in micropores [28]. The reduction in OMC may be attributed to the decrease in specific area of the soils brought about by agglomeration of clay fractions to form silt/sand particles. The increase and decrease, respectively, in MDD and OMC for the three tested lateritic soils were also mostly affected by oven-drying at 110 °C more than oven-drying at 60 °C and air drying when compared with NMC. For instance, in charnockite-derived lateritic soil, MDD increased by 5.17 % (oven dried at 110 °C), 2.64 % (oven dried at 60 °C) and 1.51 % (air dried) when compared to the value at NMC.

4.5. *Unconfined Compressive Strength (UCS)*

The results of the UCT for the three genetically different lateritic soils as influenced by different pre-test drying temperatures are shown in Table 5. As the pre-test drying temperature increases, the UCS decreased. For lateritic soil derived from quartzite, UCS (average) decreased from an average value of 229.80 kPa (NMC) to 220.18 kPa (oven-dried at 110 °C). In lateritic soil derived from charnockite, UCS (average) decreased from 287.60 kPa to 270.68 kPa for NMC and oven-dried at 110 °C conditions, respectively.

Although the MDD of the soils increased with increase in pretest drying temperature, the lateritic soils seemed to lose their strength as the temperature increases. Similar observations have already been reported by various researchers [29], [30]. The reduction in strength may be attributed to the alteration/destruction of soil structure and loss of soil cohesion due to aggregation and clustering of the soil particles. Lateritic soils are known to partially derive their strength from cohesion, increase in particle aggregation due to increase drying tempera-

Table 5: Variation of UCS of the Lateritic Soils with Pre-test Drying Temperature

Parent rock	NMC	Air Dried	UCS (kPa) Oven Dried at 60 °C	Oven Dried at 110 °C
Quartzite	229.40	218.81	223.40	218.80
	228.40	222.90	221.40	217.90
	230.50	229.42	225.90	228.30
	230.90	223.40	220.80	215.70
	229.80	223.60	222.90	220.20
Average	229.80	223.63	222.88	220.18
Charnockite	286.80	275.30	272.77	272.30
	285.60	275.60	280.80	275.30
	290.10	276.40	276.40	264.90
	287.90	278.20	270.50	270.20
	287.80	276.40	275.10	270.70
Average	287.60	276.38	275.12	270.68
Granite	263.80	252.40	253.80	252.40
	265.90	250.20	252.90	241.80
	261.70	253.40	251.40	249.40
	264.90	257.10	250.30	245.30
	264.10	253.10	252.20	247.30
Average	264.08	253.23	252.10	247.23

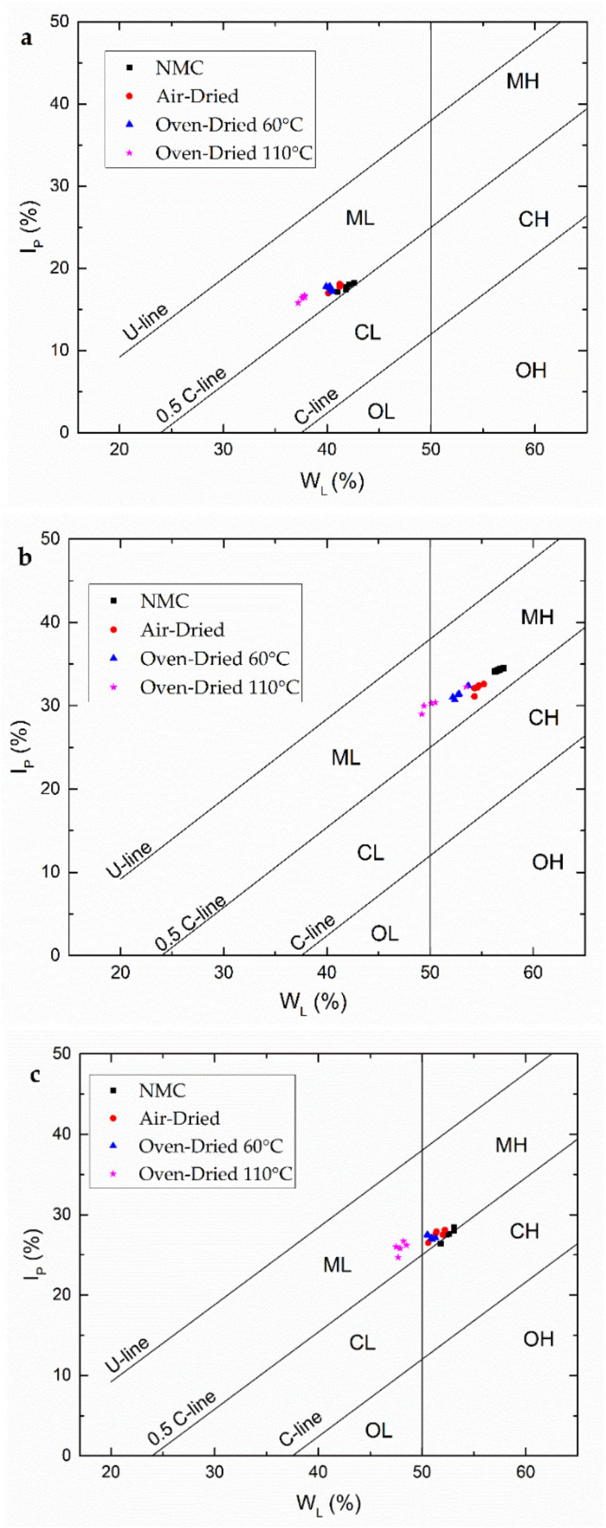

Figure 2: Polidori Plasticity Classification of the lateritic Soil. a) Quartzite-derived lateritic soil b) Charnockite-derived lateritic soil c) Granite-derived lateritic soil. CL: Inorganic clays of low plasticity, CH: Inorganic clays of high plasticity; ML: Inorganic silts of low compressibility; MH: Inorganic silts of high compressibility

ture will likely cause a loss in cohesion, hence a loss in UCS. Similar to other properties, oven drying at 110 °C produced the highest percentage reduction in UCS. In granite derived lateritic soil, for instance, the average UCS decreased by 6.27 % (oven dried at 110 °C), 4.49 % (oven dried at 60 °C) and 4.05 % (air-dried) when compared to the value at NMC. In quartzite derived lateritic soil, the average UCS decreased by 4.19 %, 3.01 % and 3.23 %, respectively, when oven dried at 110 °C, oven dried at 60 °C and air-dried.

4.6. *Free Swell Index*

The free swell is a simple test used for estimating the swelling potential of a soil. The values of FSI for the three lateritic soils are shown in Table 6. It is observed that the maximum value of FSI for the lateritic soils was at 60 °C oven drying. This was followed by FSI of samples oven-dried at 110 °C and air-dried samples except in quartzite derived lateritic soil.

Table 6: Free swell index of the lateritic soils

Parent rock	NMC	Air Dried	Oven Dried at 60 °C	Oven Dried at 110 °C
Quartzite	38.89	42.11	47.62	42.11
	40.00	42.86	45.45	40.00
	38.89	42.11	45.45	40.00
	36.84	40.00	46.00	40.90
	39.00	41.90	45.90	41.20
Average	38.72	41.79	46.09	40.84
Charnockite	42.11	45.00	52.38	47.37
	42.11	45.00	54.55	50.00
	44.44	50.00	52.38	47.37
	42.11	42.11	53.70	48.30
	42.80	46.00	52.50	49.00
Average	42.71	45.62	53.10	48.41
Granite	42.86	45.45	50.00	47.83
	45.45	47.83	50.00	47.83
	42.86	45.45	52.17	50.00
	43.48	45.83	51.50	48.20
	44.00	46.30	49.80	49.00
Average	43.73	46.17	50.69	48.57

The increase in FSI up 60 °C oven drying may be due to the clay minerals present in the soil developing a high repulsive force with increasing temperature. Consequently, according to Basma *et. al.* [6], "this caused the clay particles to separate more and developed a flocculated structure which led to more water being needed to make up for the deficiency upon wetting and hence more swelling". The decrease in FSI when the pre-test temperature increased from 60 °C to 110 °C may be due to loss of plasticity and increasing aggregation of the soils.

5. Conclusions

In this present study, the effect of pre-test drying temperature on the properties of lateritic soils was examined. For this reason, three genetically unrelated lateritic soils were selected for this study. Three pre-test drying temperatures were used and this includes air-drying, and oven-drying at both 60 °C and 110 °C. Different tests were carried out on the three lateritic soils to study the influence of the aforesaid pre-test drying temperatures on particle size, specific gravity, consistency limits, free swell, compaction parameters, and strength properties. The index and engineering properties at their NMC are influenced by the parent rock factors. Drying the lateritic soils to 110 °C reduced the plasticity index, specific gravity, clay content, liquid limit, OMC, and unconfined compressive strength of the lateritic soils. The decrease in properties such as plasticity index, OMC and unconfined compressive strength may be attributed to particle aggregation (which reduced the soil surface are) and loss of cohesion. This study also revealed that lateritic soils dried at 110 °C may lead to underestimation of the UCS. The increased in pre-test drying temperature slightly reduced the silt content and plastic limit of the soils. The pre-test drying temperature did not significantly change the soils' plasticity classification, however, at higher pre-test temperature (namely 110 °C) the soils are generally less plastic. The MDD and sand content of the soils increased as the pre-test drying temperature increases. In general, the free swell index of the lateritic soils increased with increasing pre-test drying temperature (up to 60 °C) before decreasing when the temperature rose to 100 °C. The study has shown the effect pre-test drying temperature may have on the properties of lateritic soils. However, the fact that in most engineering and earthworks, materials wined are normally stockpiled. This process of stockpiling normally leads to some sort of air-drying. Finally, it can be concluded that air-drying seems more suitable as pre-test heating method because it will reflect the in-situ field condition.

References

[1] R. K. Goswami & C. Mahanta, "Leaching characteristics of residual lateritic soils stabilised with fly ash and lime for geotechnical applications", Waste Management **27** (2007) 466. doi: 10.1016/j.wasman.2006.07.006.

[2] M. D. Gidigasu, Laterite Soil Engineering: Pedogenesis and Engineering Principles. New York: Amsterdam Elsevier Scientific, (1976)

[3] G. O. Adeyemi, "The influence of parent rock factor on some engineering index properties of three residual lateritic soils in Southwestern Nigeria", Bulletin of the International Association of Engineering Geology **52** (1995) 3. doi: 10.1007/BF02602677.

[4] S. M. Rao, A. Sridharan & S. Chandrakaran, "Influence of drying on the liquid limit behaviour of a marine clay", Géotechnique **39** (1989) 715. doi: 10.1680/geot.1989.39.4.715.

[5] N. S. Pandian, T. S. Nagaraj & G. L. Sivakumar Babu, "Effects of drying on the engineering behaviour of Cochin marine clays", Geotechnique **41** (1991) 143. doi: 10.1680/geot.1991.41.1.143.

[6] A. A. Basma, A. S. Al-Homoud & E. Y. Al-Tabari, "Effects of methods of drying on the engineering behavior of clays", Appl Clay Sci **9** (1994) 151. doi: 10.1016/0169-1317(94)90017-5.

[7] A. I. Husein Malkawi, A. S. Alawneh & O. T. Abu-Safaqah, "Effects of organic matter on the physical and the physicochemical properties of an illitic soil", Appl Clay Sci **14** (1999) 257. doi: 10.1016/S0169-1317(99)00003-4.

[8] E. Uyeturk & N. Huvaj, "Drying Changes Consistency Limits", in Geo-Congress **2019** (2019) 532. doi: 10.1061/9780784482124.054.

[9] K. Terzagi, R. B. Peck & M. Gholamreza, Soil mechanics in engineering practice. New York: Wiley, (1996).

[10] F. Townsend, "Geotechnical Characteristics of Residual Soils", Journal of Geotechnical Engineering **111** (1985) 77. doi: 10.1061/(ASCE) 0733-9410(1985)111:1(77).

[11] S. Nayak & H. K. Preetham, "Effect of Drying Temperature and Rewetting on the Engineering Properties of Marine Clay", Transportation Infrastructure Geotechnology **7** (2020) 517. 10.1007/s40515-020-00105-y.

[12] A. Zelalem, *Basic Engineering Properties of Lateritic Soils Found in Nejo – Mendi Road Construction Area, Welega*, MSc thesis, Addis Ababa University, Ethiopia, (2005).

[13] M. D. Gidigasu, "Degree of weathering in the identification of laterite materials for engineering purposes", Engineering Geology **8** (1974) 213.

[14] A. Elueze, "Compositional appraisal and petrotectonic significance of the Imelu banded ferruginous rock in the Ilesha schist belt, southwestern Nigeria", Journal of Mining and Geology **36** (2020) 9.

[15] L. O. Afolagboye, "Using index tests to predict the compressive strength of crystalline rocks", Proceedings of the Institution of Civil Engineers - Construction Materials **174** (2021) 289. doi: 10.1680/jcoma.18.00061.

[16] L. O. Afolagboye, Y. A. Abdu-Raheem, D. E. Ajayi & A. O. Talabi, "A comparison between the consistency limits of lateritic soil fractions passing through sieve numbers 40 and 200", Innovative Infrastructure Solutions **6** (2021) 97. doi: 10.1007/s41062-020-00427-3.

[17] L. O. Afolagboye, A. O. Talabi & O. O. Akinola, "Evaluation of selected basement complex rocks from Ado-Ekiti, SW Nigeria, as source of road construction aggregates", Bulletin of Engineering Geology and the Environment **75** (2016) 853. doi: 10.1007/s10064-015-0766-1.

[18] G. O. Adeyemi, L. O. Afolagboye & C. O. Ezenwafor, "Engineering Geological Evaluation of some Soils from Ozubulu, Near Onitsha, SE Nigeria for use as a Liners in Waste Disposal Landfill", Journal of Mining and Geology **50** (2014) 109.

[19] British Standard 1377, Methods of test for soils for civil engineering purposes. London: British Standards Institution, (1990).

[20] A. S. Rao, B. R. Phanikumar & R. S. Sharma, "Prediction of swelling characteristics of remoulded and compacted expansive soils using free swell index", Quarterly Journal of Engineering Geology and Hydrogeology **37** (2004) 217. doi: 10.1144/1470-9236/03-052.

[21] W. Holtz & H. Gibbs, "Engineering Properties of Expansive Clays", Transactions ASCE **121** (1956) 641. doi: 10.1038/nn.2886.

[22] B. M. Sunil & H. Krishnappa, "Effect of Drying on the Index Properties of Lateritic Soils", Geotechnical and Geological Engineering **30** (2012) 869. doi: 10.1007/s10706-012-9504-7.

[23] M. V. Villar & A. Lloret, "Influence of temperature on the hydro-mechanical behaviour of a compacted bentonite", Appl Clay Sci. **26** (2004) 337. doi: 10.1016/j.clay.2003.12.026.

[24] B. M. Sunil & A. V. Deepa, "Influence of Drying Temperature on Three Soils Physical Properties", Geotechnical and Geological Engineering **34** (2016) 777. doi: 10.1007/s10706-016-0001-2.

[25] I. Jefferson & C. D. Foss Rogers, "Liquid limit and the temperature sensitivity of clays", Engineering Geology **49** (1998) 95. doi: 10.1016/S0013-7952(97)00077-X.

[26] E. Polidori, "Relationship between the Atterberg limits and clay content", Soils and Foundations **47** (2007) 887. doi: 10.3208/sandf.47.887.

[27] L. O. Afolagboye, A. O. Talabi & O. O. Owoyemi, "The use of Polidori's plasticity and activity charts in classifying some residual lateritic soils from Nigeria", Heliyon **7** (2021) e07713. doi: 10.1016/j.heliyon.2021.e07713.

[28] Z. Chen, H. Zhu, Z. Yan, L. Zhao, Y. Shen & A. Misra, "Experimental study on physical properties of soft soil after high temperature exposure", Engineering Geology **204** (2016) 14. doi: 10.1016/j.enggeo.2016.01.014.

[29] M. M. Abu-Zreig, N. M. Al-Akhras & M. F. Attom, "Influence of heat treatment on the behavior of clayey soils", Appl Clay Sci. **20** (2001) 129. doi: 10.1016/S0169-1317(01)00066-7.

[30] I. C. Attah & R. K. Etim, "Experimental investigation on the effects of elevated temperature on geotechnical behaviour of tropical residual soils", SN Appl Sci. **2** (2020) 370. doi: 10.1007/s42452-020-2149-x.