International Journal of Materials Science and Applications
2023; 12(4): 52-58
http://www.sciencepublishinggroup.com/j/ijmsa
doi: 10.11648/j.ijmsa.20231204.12
ISSN: 2327-2635 (Print); ISSN: 2327-2643 (Online)

Geochemical, Geotechnical, Mineralogical and Microstructural Properties of the Cubitermes Sp Termite Mound Soil for Its Use in Construction

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To cite this article:
Louis Ahouet, Sylvain Ndinga Okina, Adolphe Ekouya. Geochemical, Geotechnical, Mineralogical and Microstructural Properties of the Cubitermes Sp Termite Mound Soil for Its Use in Construction. *International Journal of Materials Science and Applications*. Vol. 12, No. 4, 2023, pp. 52-58. doi: 10.11648/j.ijmsa.20231204.12

Received: August 30, 2023; **Accepted**: September 15; **Published**: September 27, 2023

Abstract: The geotechnical properties (grain size, Atterberg limits, compressive strength, CBR, linear swelling, static modulus, hydraulic conductivity, SSA, CEC, activity) of the cubitermes sp termite mound soil were determined. X-ray diffraction, scanning electron microscopy coupled with EDS and energy dispersive X-ray spectrometry were used. The results show that the soil is composed of kaolinite, illite, chlorite and intermediate layers of rutile-quartz-hematite. Although the sand content of the soil is less than the minimum of 30% and the compressive strength is CS (3.89 MPa), termite mound soil can be used to make adobe bricks or compressed earth bricks. Termite mound soil is very consistent and impermeable, making it ideal for earthworks. Despite its CBR (33%), the soil contains 7.2% organic matter, well above the 2.5% standard for use as a pavement sub base layer. The soil has an Ac activity (0.603) and a 75% fines content, so lime would be better suited to this soil than cement in the process of improving mechanical properties. X-ray fluorescence analysis shows that the major elements are alumina and silica, which make up the soil's skeleton. The presence of alumina in the soil causes it to swell, which may limit its use in road construction. The presence of Al, Mg and Fe proves the respective existence of aluminum, magnesium and iron oxides in the soil. Titanium present in the soil in oxide form (TiO_2).

Keywords: Road Construction, Geotechnical Properties of Soil, Cubitermes Sp Termite Mound Soil, Soil Activity

1. Introduction

Cubitermes sp termite mounds are dwellings built by termites to protect themselves from predators and bad weather. Clayey soils are often used by termites to build Cubitermes sp termite mounds, making them resistant to precipitation. To build termite mounds, termites can dig up soil from a depth of ten meters [1]. Termites use soil mixed with their saliva to build termite mounds. The resulting mixture can modify the clay content, bulk density, water retention capacity and structural stability of the termite mound. Termite action can also alter the organic matter content, specific surface area and cation exchange capacity of the soil. The feeding habits of termites can modify the activity and diversity of microbial communities and the land-use properties of soils. Cubitermes sp termite mounds can resist for up to 100 years after the termites have left. The nests of Cubitermes sp termite mounds are mushroom-shaped, 30 to 50 cm in diameter and up to 50 cm high. The presence of termite mounds per unit area from one site to another is highly variable and generally low in forest areas and wet soils [1, 2]. The presence of termites and the microbial population in a termite mound has a synergistic effect on the decomposition of organic matter. The abundance of Cubitermes sp termite mounds and their physic-chemical properties justify their use in fertilizing agricultural soils [3-5]. However, the scarcity of suitable conventional construction materials has led to the use of Cubitermes sp termite mounds soil (a non-conventional material) in the large-scale construction of an earth road in Congo [6]. This use was motivated mainly by the availability of soil from Cubitermes sp termite mounds in the savannah zone. However, this application was not preceded by extensive laboratory testing. Experience has shown that the use of local materials comes up against difficulties linked to their geotechnical properties, which sometimes do not meet the requirements of current standards. The properties of Cubitermes sp termite mound soil generally depend on the surrounding soils [7]. Natural soils suitable for construction are not widely available and the cost of transporting them far from their source is sometimes prohibitive. The use of the cubitermes sp termite mound soil in construction is an alternative solution to the lack of suitable materials.

The aim of this work is to characterize the properties of cubitermes sp termite mound soils in accordance with conventional specifications for their use in construction. To this end, the geotechnical, physic-chemical, mineralogical and microstructural characteristics of the soil were determined.

2. Materials and Methodology

2.1. Materials

The cubitermes sp termite mound soil was sampled in the Republic of Congo, according to the geographical coordinates 5°45' East and 2°29' South (Figure 1).

Figure 1. *Cubitermes sp termite mound soil.*

2.2. Methodology

After sample collection, the cubitermes sp termite mound soil was crushed and sieved to retain only grains with a diameter of less than 2 mm.

The granulometric analysis of the soil was carried out in accordance with standards NF P94-056 [8] for grains larger than 80 µm and NF P94-057 [9] for grains smaller than 80 µm. The granulometric fraction is deduced from the recommendations of the granularity nomograms considering clays as particles smaller than < 0.002 mm, silt 0.002-0.06 mm and sand 0.06-2 mm.

The Atterberg limits (plasticity limit, liquidity limit, plasticity index) of the natural soil were determined according to standard NF P 94-051 [10] and the SBV soil blue value according to standard NF P94-068 [11].

Soil activity, defined as the ratio between the plasticity index (PI) and the clay fraction CF < 0.002 mm (Ac = PI/CF), Skempton A. W. (1953) [12]

Specific surface area (SSA) and cation exchange capacity (CEC) are two fundamental properties that dominate the behavior of fine soils, defined by the respective formulae SSA (m^2/g) = 20.93*SBV and CEC (meq/100g) = SBV*1000/374.

The maximum dry density MDD and optimum moisture content OMC are determined in accordance with standard NF P 94-093 [13].

To determine the compressive strength CS at 28 days in accordance with standard NF P98-230-2 [14], six cylindrical specimens 7.5 cm in diameter and 15 cm long are made at the optimum moisture content and hardened at an average ambient temperature of 25°C. The static modulus was determined by the ratio between the compressive strength and the strain at failure of the material.

The CBR index and the linear swelling of the soil were determined in accordance with standard NF P94-078 [15].

Scanning electron microscopy (SEM) coupled with EDX is carried out using a Phillips XL30 EM electron microscope, which provides information on the relief of the sample, the morphology of the grains and their arrangement in the material. In addition, an energy dispersive spectrum (EDX) provides semi-quantitative information on the chemical composition of the material examined.

A Hermo Niton FXL X-ray fluorescence spectrometer equipped with a silver anode and an RX50 kV/400µA/10 W tube was used to determine the content of chemical constituents in the soil. Before analysis, the samples were dried and then compressed into pellets. Analyses were carried out under helium to increase sensitivity to light elements.

Differential Thermal Analysis (DTA) used observe physic-chemical transformations material function temperature. It consists measuring heat released or absorbed material during its transformation applying thermal cycle-controlled rate. Difference between temperature sample and that thermally inert reference reveals endothermic peaks. Thermogravimetric analysis (TGA) allows study mass variations during thermal cycle, linked chemical reactions departure volatile constituents adsorbed or combined material. Temperatures at which these mass losses occur provide complementary information to that obtained by DTA for identification physicochemical phenomena involved and crystalline phases involved. Two characterizations were carried out simultaneously same apparatus. Soil was finely ground particle size of less than 2 µm.

3. Results

3.1. Geotechnical Properties of the Cubitermes sp Termite Mound Soil

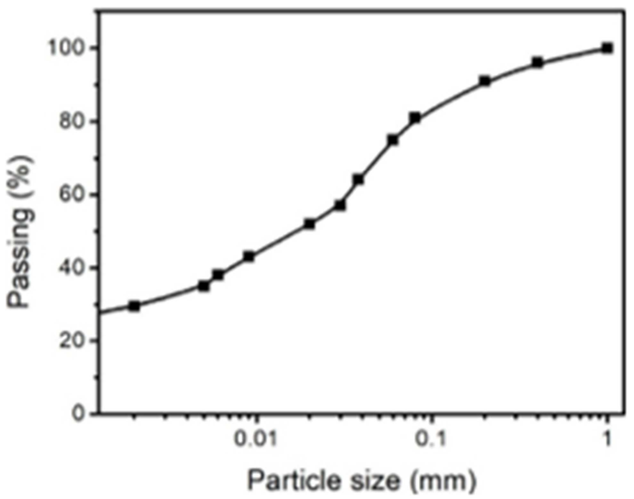

Figure 2. *Particle size distribution of cubitermes sp. termite mound soil.*

The granulometric curve is oblique, made up of clay, silt and sand likely to be used on building sites on service roads for the passage of machinery. According to Figure 2, the maximum grain size is between 0.5 and 10 mm, and the soil contains too many fine particles (75%). The contents of clay, silt (fine, medium, coarse) and sand (fine, medium, coarse) are shown in Table 1.

Table 1. *Distribution of grains in the Cubitermes sp termite mound soil.*

Particle size fractions (%)								
Clay	**Silt**	**Sand**	**Fsi**	**Msi**	**Csi**	**Fsa**	**Msa**	**Csa**
29.45	45.12	25.43	8.89	13.28	22.95	15.79	7.35	2.29

Clay, Silt, Fsi – fine silt, Msi – medium silt, Csi – Coarse silt, Sand, Fsa – fine sand, Msa – medium sand, Csa – coarse sand

Table 1 shows that the clay content of this soil is within the range recommended for the manufacture of adobe bricks and compressed earth bricks CEB.

Table 2. *Geotechnical properties of cubitermes sp termite mound soil.*

Geotechnical properties	Values
Passing to 80µm (%)	75
Passing to 0.425 mm (%)	96
Plasticity limit (%)	18.44
Liquidity limit (%)	36.20
Plasticity index (%)	17.76
Plasticity modulus	1728
Blue value of the soil BVS (g/100g)	0.50
Immediate CBR %	28
Maximum dry density (t/m^3)	1.56
Optimum moisture content (%)	20
Natural water content (%)	5
CBR index %	33
Static module (MPa)	166
Linear swelling (%)	3.4
Consistency index	1.76
Organic matter (%)	7.6
Activity	0.603
Specific surface area SSA (m^2/g)	3.09
Cation exchange capacity CEC (meq/100)	1.34
Compressive strength CS (MPa) 28 days	3.89
Strain at failure	0.0185
Soil permeability (cm/s)	4.4E^{-9}
Internal angle of friction (°)	25

According to Table 2, the soil is a clayey silt, insensitive to water, moderately plastic, has a plasticity index PI (17.76%) and a blue value of the soil BVS (0.2-2.5 g/100g) [16]. However, as the ICBR is less than the minimum of 50%, the soil is considered to be an unstable material in a pavement layer [17]. The CBR (33%) at 4 days immersion is higher than the minimum of 30% for materials authorized for use in the sub-base layer for low-traffic roads [16]. The relative linear swelling of 3.4% is higher than the recommended maximum of 2.5%. The maximum dry density DDM (1.56 t/m^3) is lower than the minimum of 1.9 t/m^3 and its optimum moisture content OMC (19.65%) is higher than the maximum of 13%, values recommended for sub-base layer materials. The consistency index of $1.50 < 1.76 < 2$ means that in situ compaction of the soil will be difficult. Analysis of the cubitermes sp termite mound soil reveals that the organic matter content of 7.6% is higher than the maximum 3% permitted for road soils [16]. The soil has a specific surface area of SSA (3.09 m^2/g), i e., the material contains kaolinite [18, 19]. The specific surface area depends on the mineralogy, organic composition and texture of the soil and the cation exchange capacity CEC (1.34 meq/100g). Bigorre et al (2000) [20] obtained data on 50 different horizons, showing that CEC and SSA values depend on the nature of the clays, but also on the surface electrical charges developed by the organic matter. The material was sampled during the dry season, and has a natural water content of 5%.

Table 3. *Chemical composition of soil obtained by X-ray fluorescence.*

Chemical composition	(%)
SiO_2 (%)	51,633
Al_2O_3 (%)	17,057
Fe_2O_3 (%)	7,229
Ca (%)	0,398
MgO (%)	LOD
K_2O (%)	LOD
TiO_2 (%)	2,211
MnO (%)	0,016
Sr (%)	0,002

According to Table 3, the cubitermes sp termite mound soil is composed essentially of silica (51.633%), alumina (17.057%) and iron oxide (goethite) in small quantities

(7.229%). X-ray fluorescence analysis shows that silica and alumina are major elements in the cubitermes sp termite mound soil.

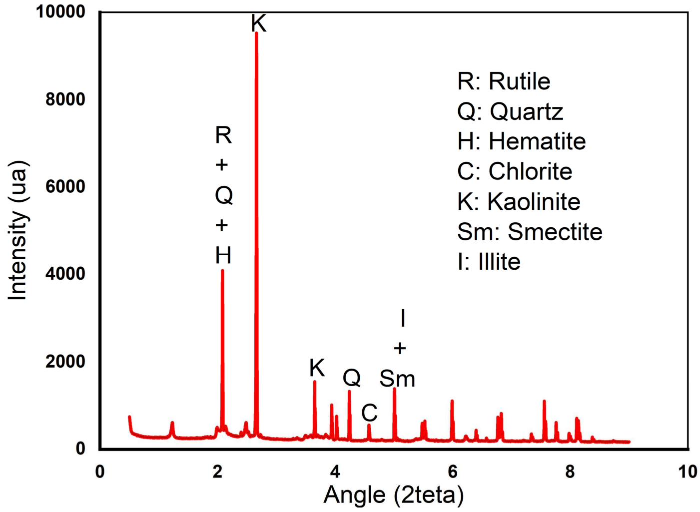

Figure 3. *X-ray diffractogram of the cubitermes sp termite mound soil.*

From Figure 3, analysis of the X-ray diffractogram shows that quartz is present in the sample in minimal quantities. The cubitermes sp termite mound soil is composed of the mineral's kaolinite, illite, chlorite (small quantities) and the intermediate layers rutile-quartz-hematite or smectites.

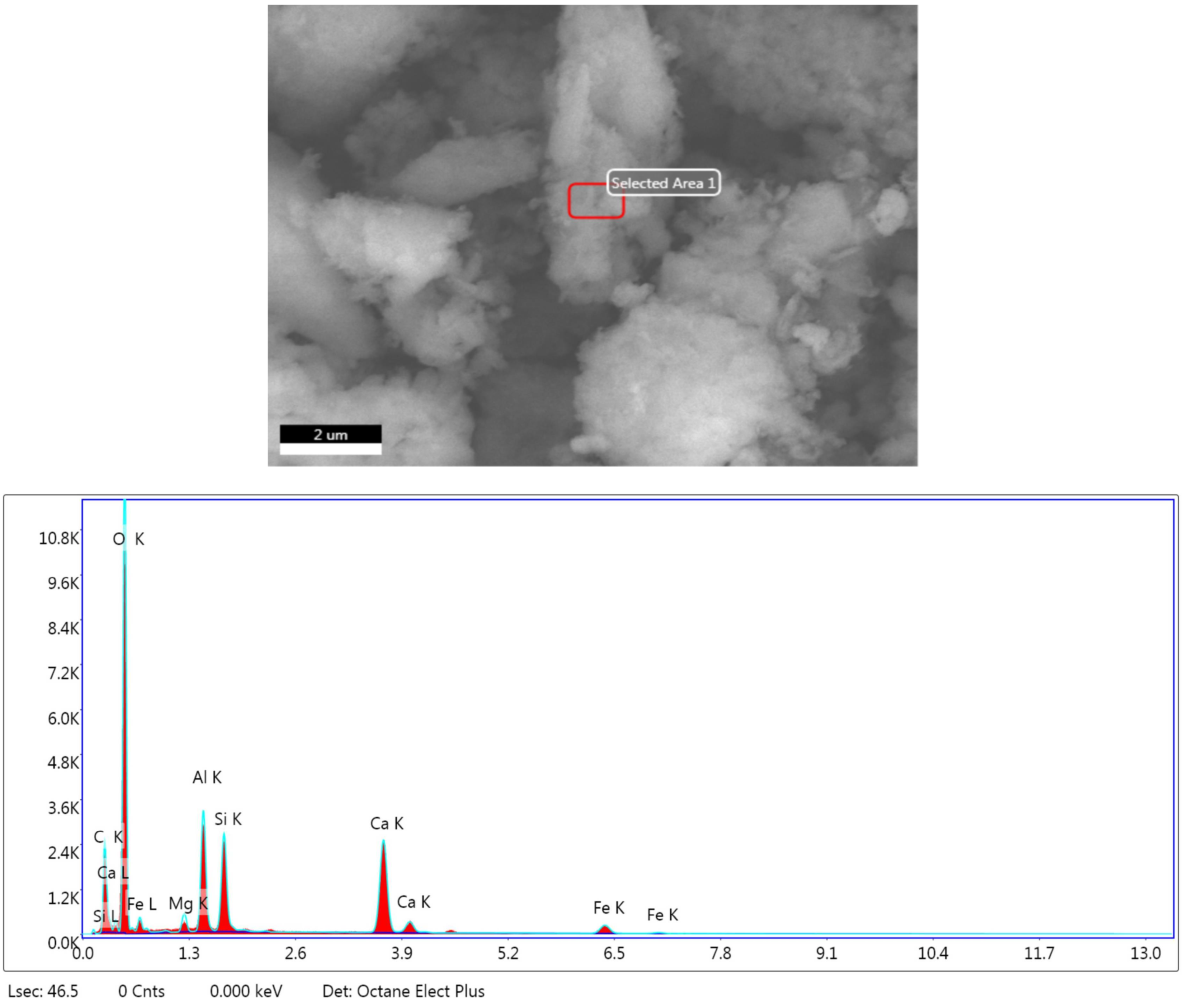

Figure 4. *Scanning electron microscopy (SEM) coupled with EDX.*

The results obtained using scanning electron microscopy (SEM) coupled with EDX are shown in Figure 4. The soil sample shows welded or bonded grains after crushing. The size of the grains would certainly depend on the texture of the surrounding soils or the size of the grains brought up from the deep horizons of these same soils by termites. There is virtually no difference in grain shape for the soil studied.

Furthermore, the results obtained from EDX analysis show that the soil contains elements such as oxygen (O), silicon (Si), potassium (K), phosphorus (P), calcium (Ca), carbon (C), aluminum (Al), iron (Fe) and titanium (Ti). These elements do not exist as single chemical elements in the soil sample analyzed. We can say that the soil grains that termites bring up from deep horizons to build their nests depend on the mineralogical composition of the soil. The presence of carbon (C) in the soil is undoubtedly due to the presence of organic matter. The presence of silicon (Si) is proof of the existence of silica, as it is present in quartz, but also of the presence of minerals such as kaolinite. The presence of Al, Mg and Fe not only proves the respective existence of aluminum, magnesium and iron oxides in the soil studied. However, their existence as compensating cations in the clay plates, which can substitute either Si for Al, or Al for Fe and Mg, for a dioctahedral or trioctahedral substitution. Titanium can only exist in this soil in oxide form, generally (TiO_2). These results are in agreement with those obtained by X-ray fluorescence.

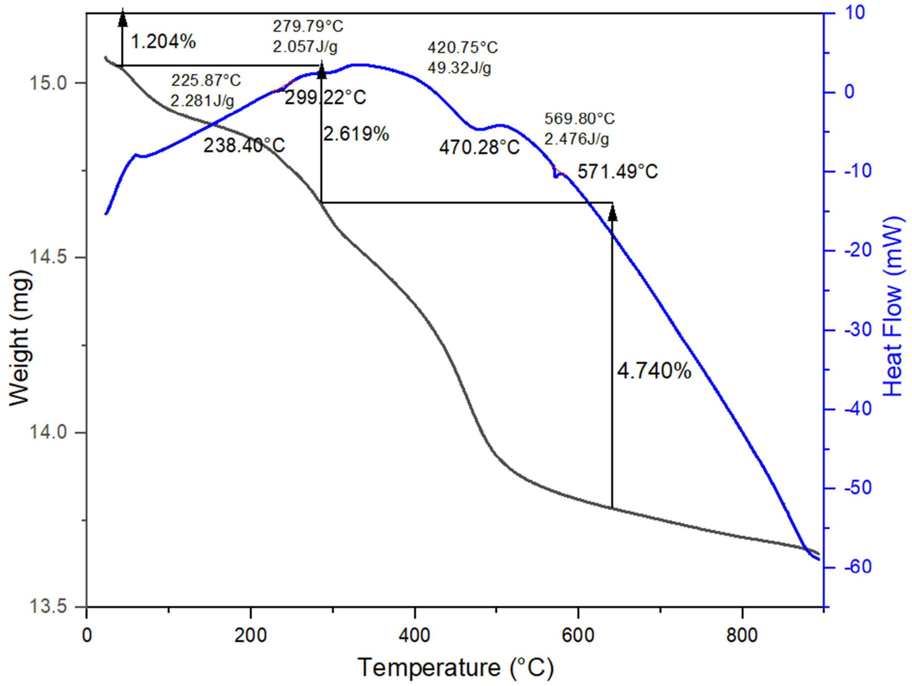

Figure 5. *Effect temperature in mass loss soil.*

The thermal accidents following the chemical changes observed on the curves in figure 5 correspond to the following transformations:

Departure of zeolitic water or coordination water marked by the endothermic peak which occurred at a temperature of 146°C. This chemical transformation is followed by a loss of mass of around 1.204%. The transformation of goethite into haematite by dihydroxylation is characterized by endothermic peaks. The DTA-GTA curves can be seen in Figure 4 at a temperature of 348°C, accompanied by a mass loss of 2.619% of the total mass of the sample.

The dihydroxylation of kaolinite showed a significant endothermic peak, clearly linked to the departure of hydroxide. The endothermic peak was located at 635°C and was followed by a mass loss of 4.740% of the average total mass of the sample.

3.2. Discussion

The sand content is below the minimum permitted for the manufacture of adobe bricks and compressed earth bricks. Indeed, for the manufacture of adobe and BTC bricks, standards recommend an average clay content of 10 to 30% and a sand content of at least 30% [21]. To correct this imbalance without significantly increasing the cost of the bricks, a hydraulic binder (lime) could be added, taking into account the 75% fines content [17]. In other words, the material can be used in earthworks [16]. The immediate CBR ICBR (28%) represents the bearing capacity of the material when laid on site. The ICBR is greater than the minimum of 20% and 25%, recommended respectively for use as a sub-base layer [17] and to compensate for unstable soils for the movement of site machinery [17]. The static modulus East (166 MPa) is lower than the minimum of 300 MPa required for the use of the material in sub-base layer [16]. Soil organic matter results from the fact that termites incorporate large quantities of excrement (rich in organic compounds) to build their termite mounds. In other words, termites build termite mounds that are much more organic. The soil activity Ac (0.60) is less than 0.75, which means that the material is inactive [18]. Inactive soils do not absorb water, which makes them difficult to handle. With a soil activity above the minimum of 0.50, cubitermes sp termite mound soil can be treated with hydraulic binders (lime, cement). However, as termite mound soil contains 75% fines, lime would be better suited to this soil than cement.

Compressive strength CS (3.89 MPa) is higher than the minimum of 2 MPa for the manufacture of adobe bricks and compressed earth bricks. At 28 days, water reduction decreases, which explains the increase in mechanical strength from 3 to 28 days. Compressive strength CS (2.16 - 3.89 MPa) at 28 days increases by 80%. With compressive strengths in excess of 1.75 MPa, the soil can be used as a sub-base layer or road earthwork material [16].

The drainage coefficient K (10^{-9} cm/s) of the soil is at the upper limit of practically impermeable soils such as unweathered homogeneous clays or clayey silts. According to Taylor's triangular diagram, the soil of the Cubitermes sp termite mound is classified as clayey silt. Impermeable soils and those with poor drainage are favourable for earthworks in civil engineering [22].

The skeleton of the cubitermes sp termite mound soil is made up of silica (51.633%) and the main source of silica is found in the clayey silt. Much of the cubitermes sp termite mound soil has a high degree of angularity. On the other hand, the presence of alumina is often the cause of soil swelling, one of the reasons that limits the use of soils in road construction. Swelling leads to cracking and loss of mechanical strength.

The presence of kaolinite in this soil can be useful for making solid bricks. Clay is renowned for its role as a mortar, especially when the soil contains organic matter. The mineral illite is necessary for burnt earth (bricks, tiles and pottery) because illite favours sintering at relatively low temperatures [23]. The presence of kaolinite and illite suggests that this soil can be used as a material for the manufacture of ceramic products.

4. Conclusion

The aim of this study is to determine the physic-chemical, geotechnical, mineralogical and microstructural properties of the cubitermes sp termite mound soil. The grading curve is oblique, composed of 29.45% clay, 45.12% silt and 25.43% sand, and the material is suitable for use in earthworks. The sand content is below the 30% minimum permitted for soils used in brick making. The material is very consistent, inactive, insensitive to water and of medium plasticity. The static modulus and maximum dry density are not suitable for use as sub-base layer material for road soils. Termite mound soil has a compressive strength of CS (3.89 MPa) and can be used to make adobe bricks and compressed earth bricks. The soil has an Ac activity (0.603) and a percentage of fines of 0.75%. Lime is the most suitable binder for improving its mechanical properties. The cubitermes sp termite mound soil is composed mainly of silica, alumina and iron oxide. The clay minerals most commonly found in the cubitermes sp termite mound soil are kaolinite, illite, chlorite and smectites or rutile-quartz-hematite interlayers. The results obtained by EDX analysis show that the soil contains elements such as oxygen (O), silicon (Si), potassium (K), phosphorus (P), calcium (Ca), carbon (C), aluminum (Al), iron (Fe) and titanium (Ti).

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