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Identification of cathedral-type termite mound materials in the locality of Abidjan

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Abstract

Termite mounds are built of raw earth by termites without the use of stabilizers or application of known stabilization methods. However, they appear to be more resistant compared to raw earth materials made by man. This study therefore aims to identify the materials of cathedral-type termite mounds in the locality of Abidjan. For this, three parts of 5 termites mounds were sampled: the nest, the wall and the surrounding soil taken as a control. 500g of samples taken from the same part of the termite mound (wall, nest, control) were mixed to form a single sample. Thus, the composite samples obtained are first subjected to granulometric analysis. The nest has a sandy clay texture identical to that of the wall. The soil surrounding the termite mounds has a clayey sand texture with a significant proportion of gravel. Then the clayiness of these structures was characterized. The nest is medium plastic, moderately clayey. The wall is moderately clayey, low plastic. The soil surrounding the termite mounds is low clayey, low plastic. Finally, their mineralogical nature revealed that the nest, the wall and the surrounding soil are composed of kaolinite, goethite and quartz.

Keywords: Termite Mounds; Wall; Nest; Control

1. Introduction

Raw earth materials are not stable when exposed to severe climatic conditions, such as rain, wind, and temperature variations. On the other hand, structures built by termites show remarkable resistance to bad weather, inspiring numerous studies. Thus, identifying the reasons for the stability of termite mounds to climatic variations could offer prospects for improving the resistance of raw earth construction materials used by humans. According to studies, two methods are the basis for the resistance of raw earth materials to rain: the use of natural stabilizers and physical stabilization methods. Thus, to stabilize adobes, Millogo et al. (2016) used cow dung. This reduced the porosity of adobes and increased their water resistance. Similarly, Yalley and Manu (2013) also used cow dung to stabilize compressed earth blocks. These bricks were stabilized with a cow dung content of 20% by weight of soil giving a dry and wet compressive strength of 6.64 and 2.27 MPa respectively. According to this author these resistances are an increase of 25% compared to unstabilized bricks. Sorgho et al., (2014) used Tannins from the decoction of *Parkia Biglobosa* pods to improve the strength of a sandy clay. Also other authors like CRAterre and Guillaud, (1995) have developed 4 compaction techniques namely static compression, dynamic compression by vibration, compression by kneading and dynamic compression by impact to improve the density and compressive strength, reduce the porosity and compressibility of raw earth materials. However, termites in the construction of termite mounds seem to use none of the methods mentioned above. They build their nest by forming pellets with particles of clay, sand (Abe et al., 2009b; Brauman et al., 2000; Garnier-Sillam et al., 1989) and other mineral materials, which they mix with biological substances that they produce themselves (Abe et al., 2009a) and stick them together, giving these remarkable structures. The objective of this article is to know the composition of the soils used by termites in general and in particular macrophage termites for the construction of their nests. Indeed, these termites build nests that are very impressive from an

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architectural point of view because of their height, their size and especially their shape. The challenge is therefore to determine the granulometric composition, the nature of the clays contained in the soils used by these termites and the behavior of these soils with respect to water.

2. Methodology

2.1. Raw Materials

The raw material for this study consists of material extracted from cathedral termite mounds. The choice of termite mound is made based on the presence of termites within the nests because their presence is synonymous with freshly handled materials that will be used for the tests. This type has 2 parts. The outer part called the wall (Figure 1b) and a central part (Figure 1b), the nest, where most of the termite resides. A third raw material is added to the wall and the nest: the soil in the vicinity of the termite mound. This soil, 1m from the base of the termite mound and at a depth of 50cm, is considered the control.



Figure 1 Cathedral termite mound: a) General view b) Different parts

2.2. Methods

The wall, the nest chamber, and the control samples were collected from and around five termite mounds located at different sites in the city of Abidjan. For each part of the termite mound (wall, nest chamber, control), 500 g of material were taken and combined to form a single composite sample. Thus, the composite samples obtained were: wall, nest chamber, and control. These different samples were subjected to particle size analysis following the method described in standard NF P 94-056, which determines the distribution of particles according to their size and the texture of the materials. The Atterberg limits and the methylene blue test were carried out according to standards NF P 94-051 and NF P 94-068, respectively. These tests provide information on the clayey nature of the soil and on the activity of the clays.

The methylene blue value (MBV) and the methylene blue activity index (MBAI) were calculated using the following formulas:

$$MBV = \frac{B}{mh/(1+w)} * 100 \dots\dots\dots (1)$$

Where :

B (g) is the mass of methylene blue introduced, calculated as $B = V \times 0.01$

V (L) is the total volume of methylene blue solution (at a concentration of 10 g/L) introduced into the suspension.

mh(g) is the mass of soil used for the test, and w is its initial moisture content determined in parallel with the test.

$$MBAI = \frac{100 * MBV}{c} \dots\dots\dots (2)$$

Where C is the percentage of the clay fraction (particle size < 2 μm) of the soil.

Mineralogical analysis of the samples was performed using a Siemens D5005 diffractometer equipped with a copper anticathode (wavelength λ = 1.542 Å). Mineral identification was carried out using *Match!* software, version 3.

3. Results and Discussion

The average values of the various results obtained from the five termite mounds were analyzed and discussed.

3.1. Particle Size Distribution

The particle size distributions of the nest interior, the wall, and the control sample are presented in Figure 2.

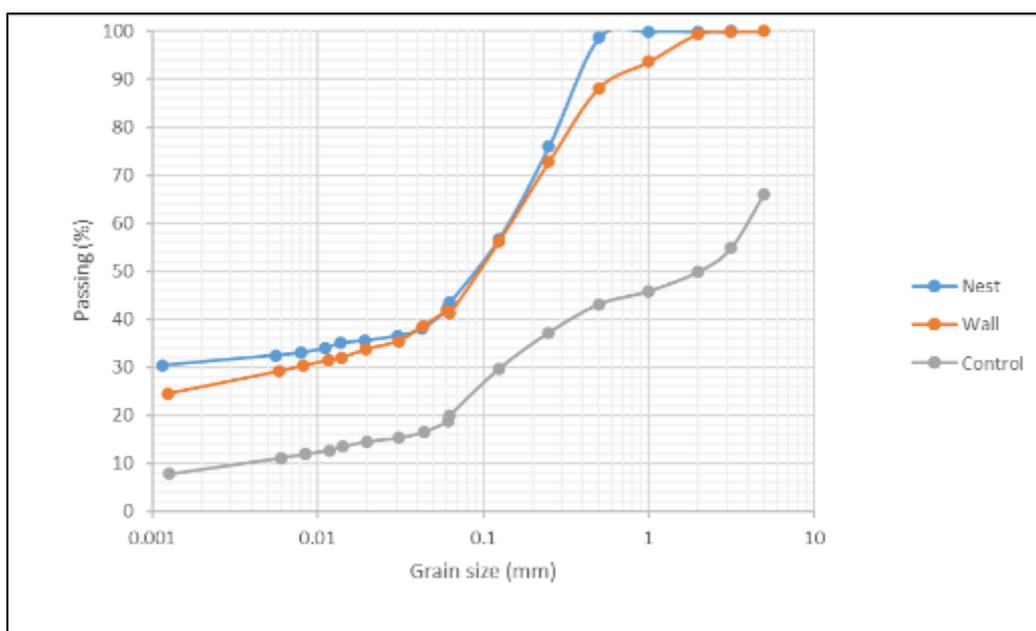


Figure 2 Particle size distribution curves of the different parts of the termite mounds

This graph shows that the termite mounds studied are composed mainly of clay particles (Particle size < 2 μm), silt (2–20 μm), and sand (Particle size between 0.02 mm and 2 mm). In contrast, the control sample also contains gravel (Particle size > 2 mm). The graph also shows that the particle size distribution curves for the nest chamber and the mound wall lie above that of the control. Consequently, the nest chamber and the wall contain more clay, silt, and sand.

The different grain size proportions of the nest chamber, mound wall, and control sample are summarized in the table below:

Table 1 Grain size classes of termite mounds and their control sample

	Gravel	Sand	Silt	Clay	Fines (Ø < 80 μm)
Nest chamber	00	56%	13%	31%	48%
Mound wall	00	58%	16%	26%	46%
Control sample	50%	30%	11%	09%	24%

This table shows that the nest chamber is richer in clay (31%) than the mound wall (26%) and the control sample (9%). Meanwhile, the mound wall contains more sand and silt (58% and 16%, respectively) than the nest chamber and the control. Termites therefore show a preference for the finer fraction of the soil. They use the more clay-rich fraction to build their nest chamber and the more sand-rich fraction to construct the mound wall.

This same result has been reported in the works of Boyer (1971), Garnier-Sillam & Harry (1995), Alain Brauman (2000), Jouquet et al. (2002, 2004), and Abe et al. (2009). These authors mention that termites carry out a particle size selection process when building their mounds. Similarly, Jouquet et al. (2003, 2004) note that *Macrotermes bellicosus*, a termite species, preferentially selects fine soil particles during mound construction in order to improve structural stability and water retention capacity. According to Boyer (1982), clay content is a limiting factor for termites when establishing themselves in soils; they disappear when the clay content of soil horizons falls below 10%.

The projection of the different grain size proportions onto the soil textural classification triangle (Cabane, 2004) (Figure 3)

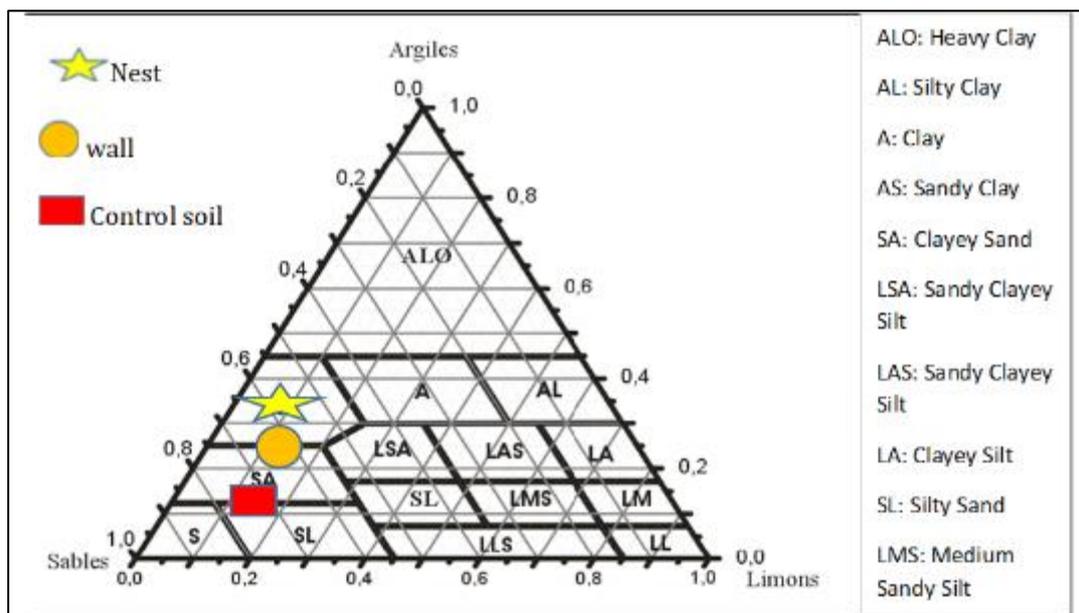


Figure 3 Casagrande textural triangle

indicates that the nest chambers and the walls are sandy clays (AS) and the controls are clayey sands (SA). There is therefore a granulometric difference between the termite mound soil and its control sample. However, in terms of texture, the wall and the nest chamber are identical. Jouquet et al. (2002, 2006) attribute this granulometric difference between termite mounds and the surrounding soil to a manipulation of soil properties by termites according to their ecological needs.

3.2. Atterberg Limits

The Atterberg limits are presented in Table 2.

Table 2 Atterberg limits of the different parts of the termite mounds

	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Nest chamber	39.55	25.55	14.0
Mound wall	33.25	22.25	11.0
Control	26.90	16.60	10.3

In this table, the nest chamber has a liquid limit of 39.55% and a plastic limit of 25.55%, while the wall has a liquid limit of 33.25% and a plastic limit of 22.25%. The control soil, on the other hand, has a liquid limit of 26.9% and a plastic limit

of 16.6%. The Atterberg limits of the control soil are lower than those of the soils used to construct the wall and the nest chamber. This confirms the more clay-rich nature of the material selected by termites for their construction.

When the Atterberg limits are plotted on the Casagrande plasticity chart (Figure 4), it appears that the nest chambers are moderately clayey and medium plastic, the walls are moderately clayey and low plastic, whereas the controls are low clayey content and low plastic. Similarly, the nest chamber is more clayey than the wall. According to Jouquet et al. (2002), the difference in plasticity between the control soils and the termite mound soils suggests a different composition of the clay fraction between termite mounds and surrounding soils. This difference in clay content and behavior suggests a greater quantity of mineralogical clay in the termite mound and a similar water sensitivity between the walls and the controls, in contrast to the nest chamber, which is more water-sensitive.

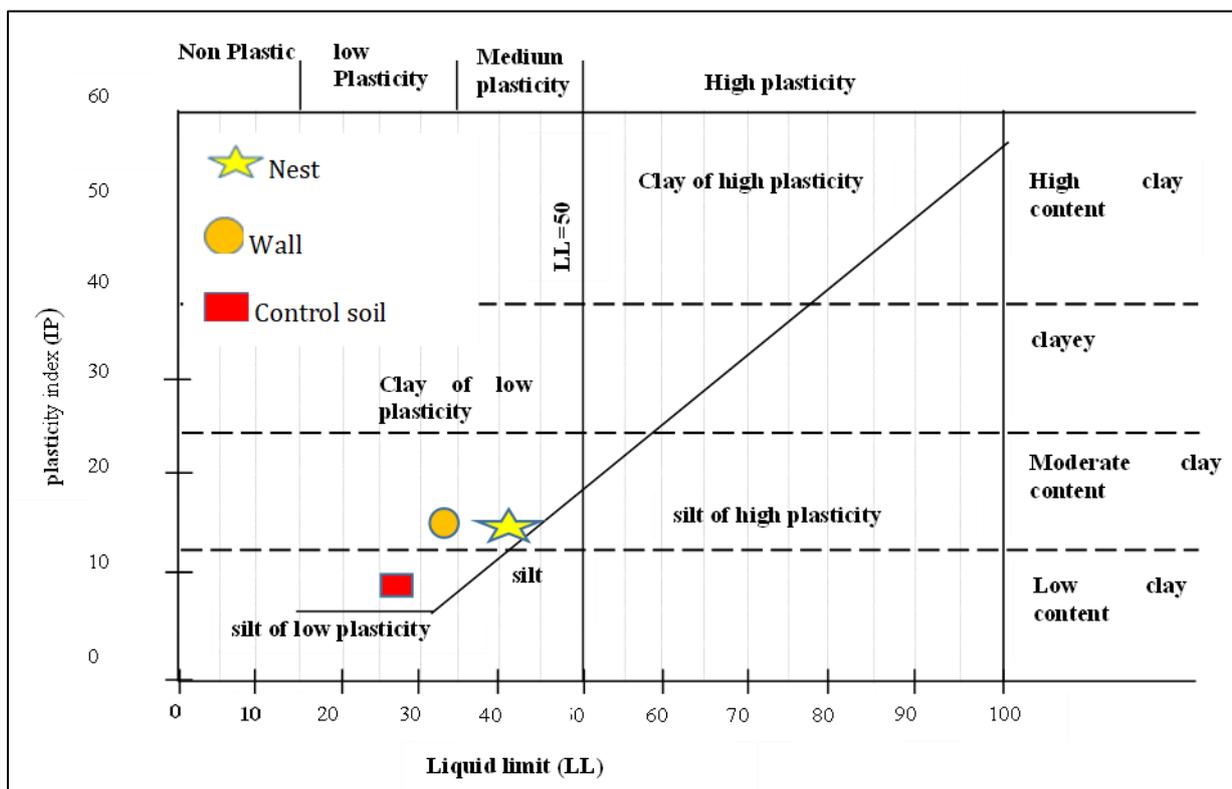


Figure 4 Casagrande plasticity chart

To assess whether the clays found in the termite mounds and in the control soil are expansive or not, their activity coefficients were also calculated according to the following formula:

$$Ac = \frac{PI}{\%clay (\% \text{ particles} \leq 2 \mu m)} \dots\dots\dots (3)$$

Table 3 presents the results obtained.

Table 3 Values of the Activity Coefficient

	Activity Coefficient (Ac)
Nest chamber	0.44
Mound wall	0.52
Control	1.3

The activity coefficient is higher in the control soils (1.3) than in the termite mound samples (wall: 0.52 and nest chamber: 0.44). The latter have an activity coefficient below 0.75. The wall and nest chamber thus contain inactive clays, whereas the controls have an activity coefficient above 0.75 and are therefore considered active (Crater, 1985). This

difference in activity, despite the fact that termites collect materials from the surrounding soil to build their mounds, could be explained by the addition of compounds by termites that modify the soil's activity.

3.3. Methylene Blue Values

Table 4 presents the methylene blue values (MBV) and the methylene blue activity index (MBAI) of the clay fraction in the termite mound and control soils.

Table 4 Methylene Blue Values (MBV) and Methylene Blue Activity Index (MBAI)

	MBV	MBAI
Nest chamber	3.2	10
Mound wall	3.1	12
Control	2.7	27

The MBV values for both termite mound and control soils range between 2.5 and 6, which corresponds to silty soils of medium plasticity. Termite mound soils are closer to the category of clay soils (MBV of 3.1 to 3.2) than the control soils (MBV of 2.7), which are closer to the threshold for low-plasticity silty soils. Furthermore, the activity index clearly distinguishes between the two soil types: with MBAI values between 5 and 13, termite mound soils are considered moderately active, while control soils are considered highly active with MBAI values above 18.

Determining both MBAI and Ac provides insight into the nature of the clays in these soils; however, the two tests yielded different interpretations. According to Ouedraogo K. (2019), this may be explained by the fact that Ac is determined from Atterberg limit tests performed on the fraction with particle sizes below 0/400 μm . This method is based on rheological measurements (liquid limit) and can be influenced by detrital materials such as silt. In contrast, MBAI, obtained from the MBV test—performed on the fraction below 0/5 mm—is based on the absorption of water by clay sheets, in which detrital materials such as silt and sand are inert.

In conclusion, based on the particle size analysis, Atterberg limits, and methylene blue values, there is a clear difference in behavior and nature between termite mound soils and control soils. These differences suggest that termites modify the soil they use for construction. Boyer (1982) supports this conclusion, stating that termites either transform clay minerals or introduce constituents into the soil that alter its activity.

3.4. Mineralogical Analyses

The X-ray diffraction spectra for the nest chamber, the wall, and the control sample are shown in Figure 5. The various identified peaks indicate that all three materials are mainly composed of kaolinite, quartz, and goethite. Therefore, there is no mineralogical difference between the termite mound samples and the surrounding soil.

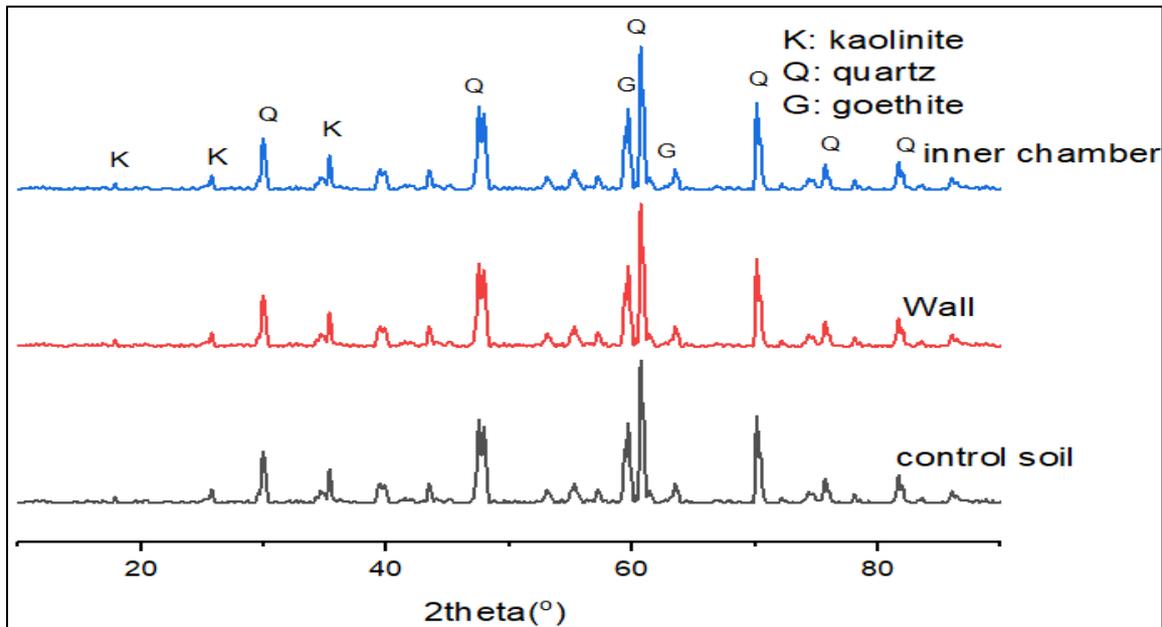


Figure 5 X-ray diagrams of the different parts of the termite mound

According to Millogo et al., (2011), quartz acts as the aggregate. It provides the overall mechanical strength of the material. Kaolinite is the mortar that binds the elements together during the construction of termite mounds.

4. Conclusion

The granulometric analysis and mineralogical composition of cathedral-type termite mounds and their surrounding soil reveal the following:

- The nest chamber contains more than 30% clay, with a sandy clay texture similar to that of the wall, which, however, is mainly composed of 58% sand. Unlike these two, the surrounding soil of the termite mounds has a clayey sands texture with a high gravel content of about 50%.
- The nest chamber has a plasticity index of 25.55%, is medium plastic, moderately clayey, with an activity coefficient of 0.44 and a methylene blue activity index of 10. The wall, on the other hand, has a plasticity index of 22.5%, is moderately clayey, low plastic, with an activity coefficient of 0.52 and a methylene blue activity index of 12. However, the surrounding soil of the termite mounds has a plasticity index of 16.6%, is low in clay, low plastic, with an activity coefficient of 1.3 and a methylene blue activity index of 27.
- Mineralogically, the nest chamber, the wall, and the surrounding soil are composed of kaolinite, goethite, and quartz.
- To build their cathedral-type structures, termites use the clayey, silty, and sandy fractions of the surrounding soil. They modify the activity of the clay fraction in order to give their constructions the desired performance.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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