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Physico-Chemical Studies of the Bricks in Mud Raw Used in the Construction of Century-Old Huts (Straw Huts): Case of the Urban Commune of Kouroussa

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Abstract: Building construction using cement bricks on the one hand, and mud bricks on the other hand, presents problems of resistance and durability in the face of natural weathering in our country (Republic of Guinea). These difficulties could be linked to non-compliance with standards and the failure to master certain physico-chemical, mechanical and technical parameters when constructing a building. In order to remedy this problem, a series of studies were carried out on samples of mud bricks used in the construction of century-old straw hut buildings in the urban commune of Kouroussa (Republic of Guinea). To this end, the compressive strength of the brick samples was assessed either: 0.10 MPa, and sensory techniques of certain characteristics were carried out to evaluate the cohesion of the elements in the brick samples, such as: coward boule technique, hand washing test, withdrawal of a soil (pellet or ring test) and of the jar test. The physico-chemical analyses methods were carried out using XRF (X-Ray Fluorescence Spectrometry), granulometry and Atterberg limits in accordance with NF P 94-051. These results showed a high insoluble residue content (49.9%) and the sample had a clay-like appearance with a low PI (Plasticity Index) = 8%. This study could be an alternative guide for the authorities in charge of housing and construction in the Kouroussa prefecture (Republic of Guinea). because, the majority of houses in Upper Guinea are built with mud raw bricks or fired bricks.

Key words: Century-old in straw hut building, raw earth brick, resistance, durability.

1. Introduction

For centuries, earth has been the first building material used in the history of mankind, because of its abundance, the use of very little energy for its maneuverability, it is too reusable with low carbon monoxide emissions and presents an economic interest as well as insulation performance and thermal comfort [1-3]. Clay bricks made of raw earth have been long time used in the architecture of buildings of the regions with hot, dry desert climates, such as certain Arab countries [4]. However, certain studies have shown that the use of raw earth bricks presented problems of resistance and of the durability of buildings constructions in material earth face of nature's bad weather on the one hand, and on the other, the failure to respect the technical parameters linked to the choice of the quality of materials which must be used in the construction of a building. This is symbolized by the massive destruction of buildings in rainy and dry (harmattan) seasons [5]. But in many towns and villages in the savannah of Upper Guinea (Republic of Guinea), there are many century-old buildings (with straw roofing) built of raw

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earth bricks without any stabilizers that, during the decades, have withstood the regions with multiple bad weather of the regions like the hot violent wind, during the day it is very cold and at night it is dry and laden with dust (harmattan) because the earth is a hygrometric regulator through its walls. However, with the urbanization of the city, these constructions in raw bricks are being replaced by cement buildings, see the mapping of case (straw hut) in raw bricks (Fig. 1).

This resistance of the mud bricks used can probably be due to many factors, such as the high presence of clay, which plays a role of natural binder in the cohesion of the various components between them that we will check, at the region's less high annual rainfall of 1,600 mm in the south and 1,200 mm in the north compared with the other regions of the Republic of Guinea: Lower Guinea 4,000 mm in August/year. This period of heavy rain causes enormous damage to the buildings in the locality; Middle Guinea 1,300 mm at the north and 2,000 mm at the south; Forest Guinea with a pluviometry long period of nine months averaging 2,500 mm/year and also to the straw used as roofing which is an excellent thermal insulator, capable of absorbing pluvial water and evacuating it slowly [6, 7]. Other results on a mixture of fibrous agricultural residues such as fonio hay, kenaf, bamboo leaf, straw and coco nut fiber with raw earth to make bricks housings have been reported [8-10]. The aim of this study is to determine of the physico-chemical parameters and mechanical characteristics of these mud bricks at raw earth used in the construction of these century-old houses (straw huts) in the urban commune of Kouroussa (Republic of Guinea) with a view to their sustainable improvement to be used in the very humid middle-income cities of the Republic of Guinea.

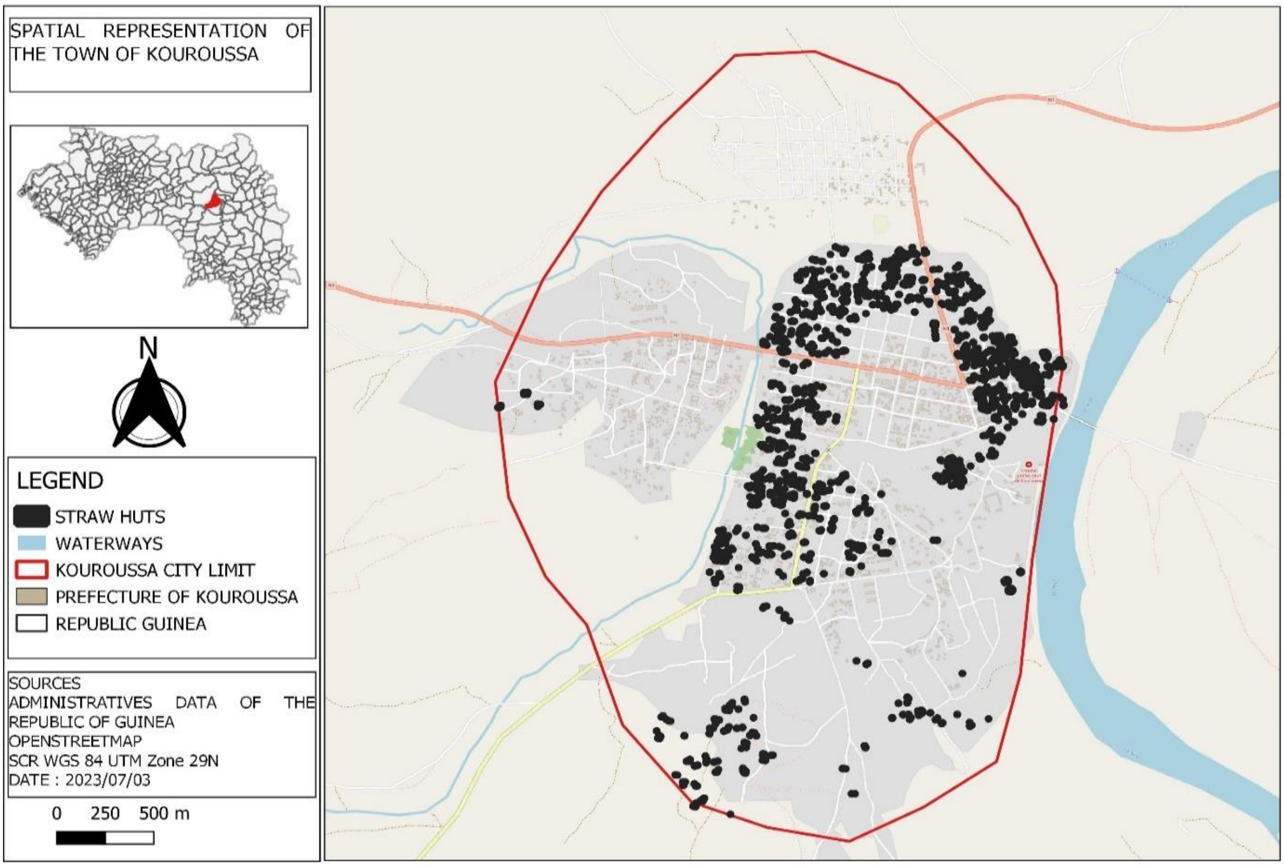

Fig. 1 Cartography showing mud brick huts (straw huts) without stabilizing black dotted on the map (urban commune of Kouroussa), other cement buildings have been omitted.

2. Materials and Methods

2.1 Presentation of the Study Area

This study was carried out in the urban commune of Kouroussa, capital of the prefecture of Kouroussa, that is a subdivision of the administrative region of Kankan in Upper Guinea (Republic of Guinea). Former chief town of a cercle in French Sudan has been attached to French Guinea on October 17, 1899. The number of inhabitants is estimated at 338,892 (according to 2014-2040 demographic projection indicators i.e., a density of 21 habitants/km^2, coordinated between 10°39′ north, 9°53′ west with an area of 1,622,000 hectares either km^2). It is subdivided into fourteen (14) sub-prefectures: Babila, Balato, Banfélé, Baro, Cisséla, Douako, Doura, Kiniéro, Komola-Koura, Koumana, Sanguiana, Kouroukoro, Kansereah and Fadou-Saba; thirteen (13) rural communes: Babila, Balato, Banfélé, Baro, Cisséla, Douako, Doura, Kiniéro, Komola-Koura, Koumana, Sanguiana, Kouroukoro, Kansereah and one (1) urban commune: urban commune of Kouroussa Fadou-Saba which still has sub-prefecture status. The Kouroussa prefecture is surrounded by five neighbouring prefectures which are: The Kouroussa prefecture is surrounded by six neighbouring prefectures who as: Kankan, Dabola, Kissidougou, Dinguiraye, Faranah and Siguiri (Fig. 2).

2.2 Study Framework

Chemistry laboratories of the Mamou Higher Institute of Technology, and Geotech Service Lanbanyi (Commune of Ratoma) has been serving framework for the study.

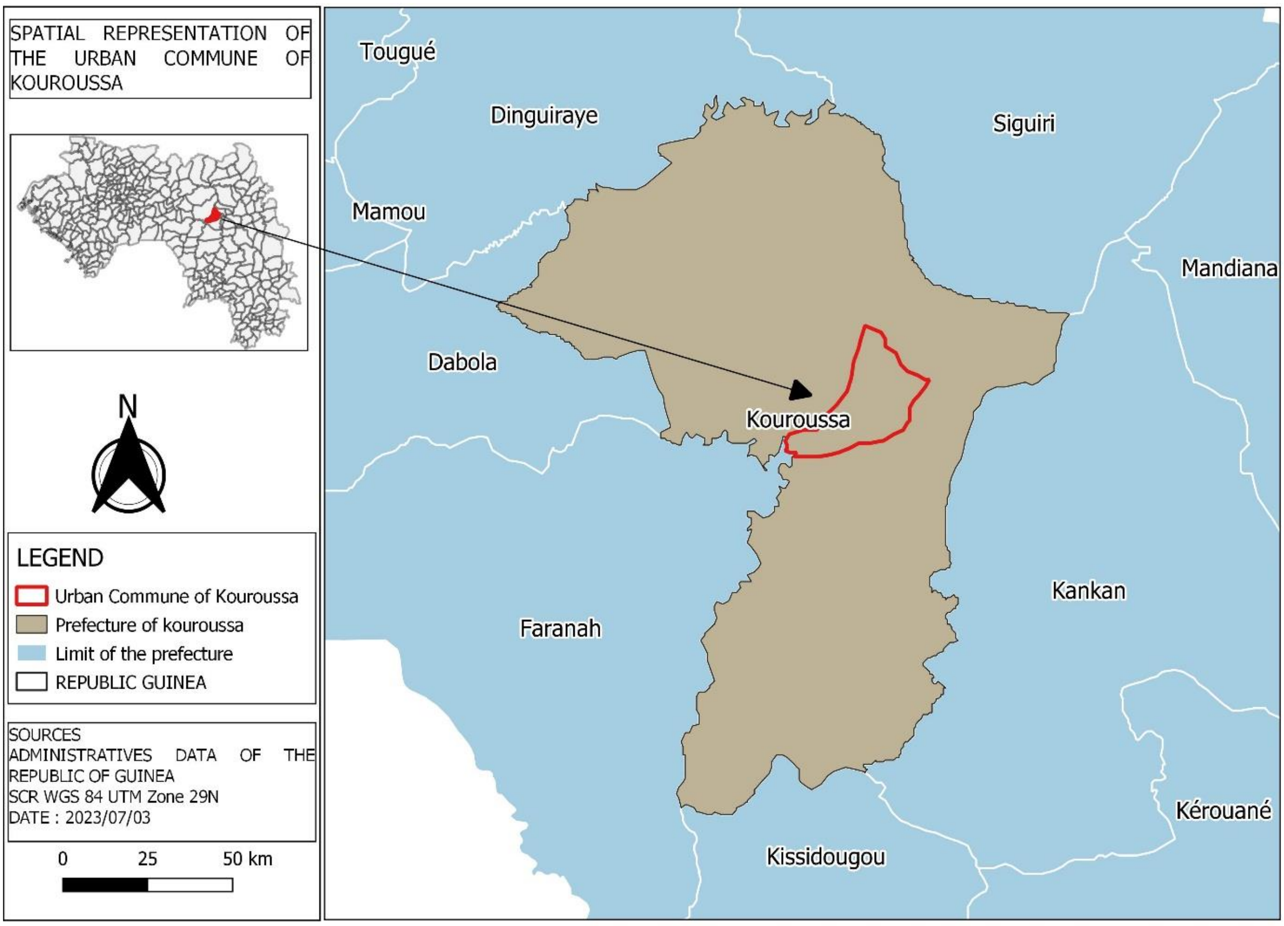

Fig. 2 Map of the Kouroussa prefecture showing the urban commune of Kouroussa.

2.3 Sampling

Mud brick used in this study was taken from hundred-year-old hut (straw hut) in the urban commune of Kouroussa (Doula sector) on April 13, 2023, located near 570 km from Conakry (capital of the Republic of Guinea). Five bricks have been collected during its demolition building for a new construction (Fig. 3). The transported bricks were used as raw materials for XRF (X-ray Fluorescence Spectrometry), physico-chemical and sensory [11-13].

Fig. 4 shows a sample of brick taken with certain measurement: length, height and its surface; another broken is for experiments.

2.4 Determination of the Brick Strength and a Few Physical Parameters (Fig. 4)

Surface; volume; volume weight; force of rupture; strength of the fracture corrected; resistance of the brick and some sensory characteristics are reported in Tables 1 and 2.

2.5 Recognition of Sensory Characteristics

2.5.1 Assessment of Cohesion

Many sensory analysis methods have been applied to assess the degree of cohesion in the brick sample to be analyzed as:

Fig. 3 Century-old straw hut before and after demolition for new construction.

Fig. 4 Sample of raw earth brick taken from this century-old straw hut.

Table 1 Results of measuring the resistance of brick with some parameters.

No.	Dimension (cm) (brick)	Weight (kg)	Surface (cm^2)	Volume (cm^3)	Weight volume g/(cm^3)	Breaking power (kN)	Correction press	Breaking power corrected (kN)	Resistance (MPa)
1	*L* = 34.5; *L* = 11.5	12.902	396.75	7,935	1.63	89	0.0424	3.77	0.10
2	*L* = 34.5; *L* = 11.75	12.915	396.75	7,935	1.63	92	0.0424	3.90	0.10
Medium		(0.10 + 0.10)/2 = 0.10 MPa or 0.10 bar							

Table 2 Recognition of visual features appreciation.

No.	Tests	Observations
1	Powdered brick	Less dusty
2	Slightly damp brick	Appreciable cohesion
3	Sensitive test	No characteristic odor
4	View after cutting	Less shiny
5	Sample bowl let go on the ground	No fissured with appreciable cohesion
6	Hand washing test	The earth part slowly when washing your hands with water
7	Removing the sample from the PVC ring	Easy removal after 6 days (Fig. 5)

hydric condition of sample, the technique of moistening a portion of earth with a little water to form a ball of earth that holds together, hands washing test, soil withdrawal (pellet or ring test) (Fig. 5), jar test (Fig. 6), sensory tests and sight after cutting. The mud bricks raw used were broken and crushed into powder.

2.5.1.1 Test Procedure of Pellet or Ring

Mix a quantity of the earth sample with water, then knead the blend to a paste (Fig. 5). Then, using your hand, fill a ring with the kneaded earth sample then compact. After six (6) days, if shrinkage is low, the risk of cracking is low. Thus, we can add a little sand to make the rendering (Fig. 5) [14].

2.5.1.2 Jar Test Procedure

Place 100 g of reduced powdered sample in a 3-L clear plastic jar, add 2.5 L of water and shake vigorously for 10 min. Leave the mixture to stand for 24 to 48 h (Fig. 6). Progressively, the successive layers are formed: sand and gravel settle at the bottom of the jar, silt forms are an intermediate layer and clay above. Organic matter and water occupy the upper part. Following on the thickness of the layers, calculate the percentage of each element taking into account the thickness of the layers as follows [15]:

$$\%\ \text{Element} = \frac{\text{Cuche thickness} \times 100}{\text{Jar thickness}}$$

2.5.2 Measuring of the Compressive Strength of the Raw Earth Brick without Stabilizing Agent

Fig. 7 shows two compression tests were carried out on two samples of raw earth brick without stabilizing agent.

Fig. 5 Sample of raw earth brick crushed and kneaded with water and easy withdrawal from the ring after six (6) days of filling.

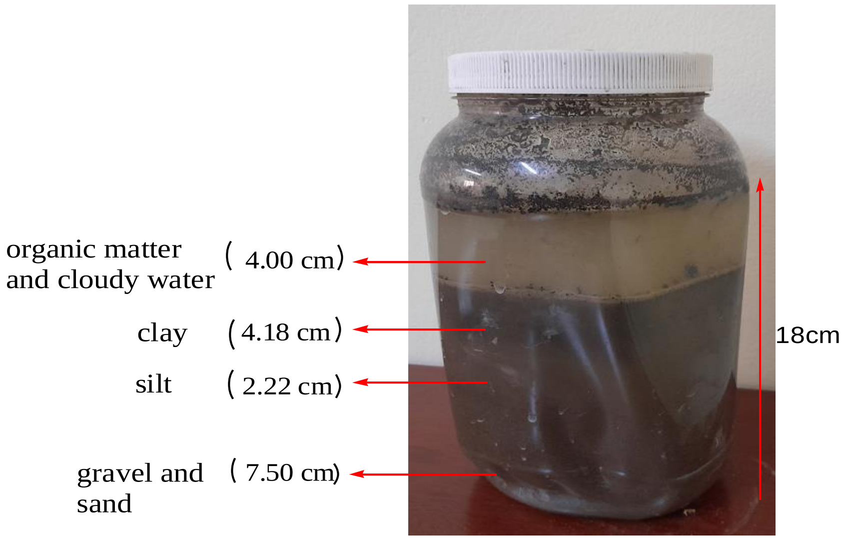

Fig. 6 The level of each element in the jar (sand and gravel; silt; clay and a mixture of water and organic matter).

Fig. 7 Testing of compressive strength for bricks.

2.5.2.1 Procedure

Place the brick, without coating, side support, between the trays of a building with mechanical load. The bricks were previously well carved so that the contact is be well done. The load and deformation values are marked immediately after the breakup [16]. The strength or resistance in MPa was determined using the formula:

$$\text{strenghth or Resistance} = \frac{\text{BF} \times \text{PC}}{\text{S}}$$

where: BF = breaking force

PC = press correction (0.0424)

S = brick surface

2.5.3 Determination of a Few Mineral Elements

Methods of chemical analysis of the brick sample have been carried in accordance with the standard: NF EN 196-2 reported in the literature [17], and XRF.

2.5.3.1 Equipment Used

Empty jar, PVC ring, XRF, 25 kg electronic density balance, CBR ring 50 press, porcelain capsule, 950 ℃ muffle furnace, water bath and filter paper.

2.5.3.2 Chemicals Products Used

Reagents: concentrated hydrochloric acid, ammonium chloride, ethanoic acid, oxalic acid, ammonium phosphate, have been purchased and used without purification.

2.5.4 Granulometric Analysis

The granulometric techniques as a column of square-mesh sieves with successive different openings from top to bottom, and a basket for the washing the sample were used (Fig. 8).

2.5.4.1 Equipment Used

Wash basket or sample preparation, square-mesh sieve, electronic balance, oven.

2.5.4.2 Procedure

Take 3 kg of brick sample, wash and dry. After drying, place the sample and mechanically shake it through a series of square-meshed sieves with successive openings from top to bottom. Coarse particles are retained above each sieve, while small particles continue their crossings. At the level of each sieve, the particles are collected and weighed using the following formulas:

$$\%\ CRe = \frac{Mc}{Mt} \times\ 100\ ;$$

$$\%\ Pby\ = \%\ Mc - 100$$

where: Mc = cumulated refusals mass;

Mt = total weight;

C_{Re} = cumulated refusals;

P_{by} = passers − by.

2.5.5 Atterberg Limits according to NF P 94-051

The best-known Atterberg Limits with bowl (liquidity limits WL; plasticity limits WP) and the IP (Plasticity Index), represent the soils identification parameters and also appreciates its Caracter clayey, mainly IP. The values found are shown in Table 3 and Fig. 9. And Granulometric curve in Fig. 10.

2.5.5.1 Equipment Used

Casagrande apparatus (bowl, stroke counts, pesky base, guide and setting mechanism, balance and groove tool), numbered and tared S B G L P and J plates (Table 5) were used.

Fig. 8 Column of sieves and basket containing washed and dried sample.

Table 3 Percentage of each element in the jar.

Elements	Thickness (cm)	Percentage obtained (%)	Water (L)	Thickness (mixture in the jar) (cm)
Sand + gravel	3.50	50.02	2	7
Silt	2.22	31.71		
Clay	4.18	59.71		
Water + organic matter	4.00	57.14		

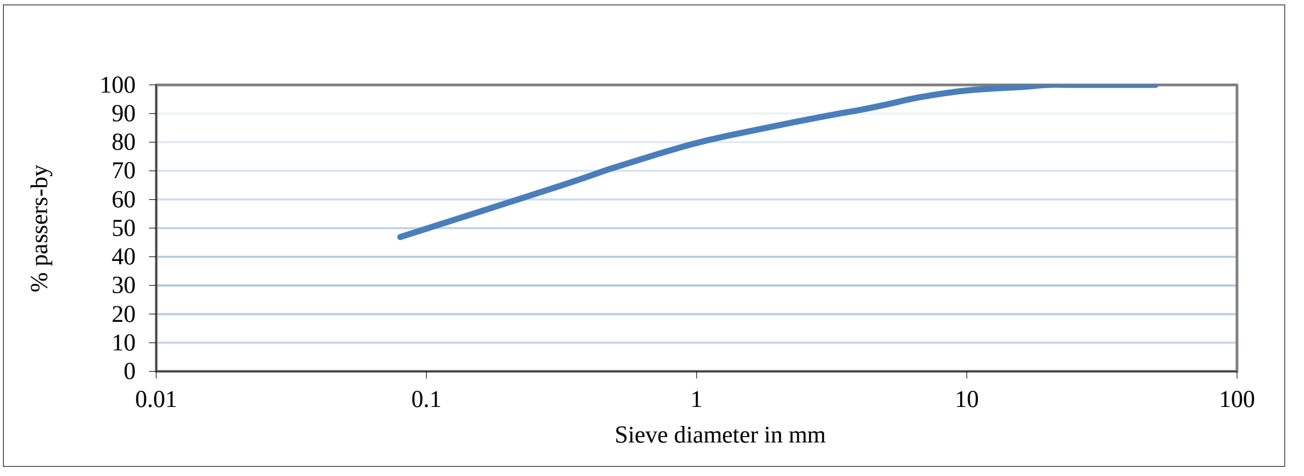

Fig. 9 Granulometric curve.

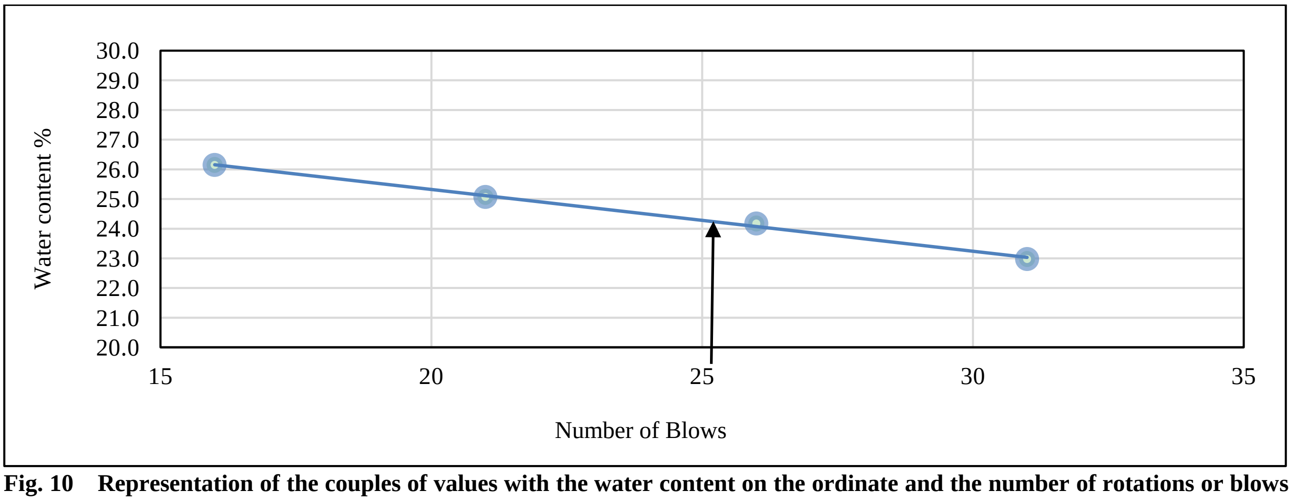

Fig. 10 Representation of the couples of values with the water content on the ordinate and the number of rotations or blows producing slot closure.

Table 4 Chemical analysis results using NF EN 196-2 code and XRF.

Elements	Symbols	Content (%)	Test reference (or as per standard) and XRF
Loss at fire	paf	10.59	EN 196-2
Insoluble residue	Rins	49.99	EN 192-2
Silica oxide	SiO_2	76.03	XRF
Alumina oxide	Al_2O_3	3.02	XRF
Ferric oxide	Fe_2O_3	9.02	XRF
Calcium oxide	CaO	5.30	XRF
Magnesium oxide	MgO	0.91	XRF
Ion sulfite	SO_3^{2-}	0.46	XRF
Chloride ion	Cl^-	0.06	EN 196-2

Table 5 Results of granulometric analysis by sieving after washing 3 kg of samples with Sieve A. F.N.O.R.

Module	Opening (mm)	Cumulative mass (g)	Refusal (%)	Passers-by (%)
	50	0.00	-	100.00
	40	0.00	-	100.00
Block	31.50	0.00	-	100.00
	25.00	0.00	-	100.00
	20.00	0.00	-	100.00

Table 5 to be continued

Gravel	16.00	22	0.73	99.27
	12.50	38	1.27	98.73
	10.00	59	1.97	98.03
	8.00	94	3.13	96.87
	6.30	144	4.80	95.20
	5.00	208	6.93	93.07
	4.00	264	8.80	91.20
Sand	3.15	316	10.53	89.47
	2.00	425	14.17	85.83
	1.00	609	20.30	79.70
	0.500	863	28.77	71.23
	0.400	956	31.87	68.13
	0.315	1055	35.17	64.83
	0.16	1322	44.07	55.93
	0.080	1594	53.13	46.87

2.5.5.2 Procedure

Take approximately 200 g of the clay brick sample; triturate, knead and crumble in order to break up the structure; add water or dry the sample to the right consistency for the test. Position the apparatus; then place the sample in the bowl to 10 mm in diameter. Groove the sample in bowl, turn the cam at ± 2 turns/s until the groove closes by about 1 cm; The rotation (or number of strokes N) should be between 15 and 40 revolutions. Take a sample of approx. 15 g at place of the closure, place it on the plates and determine its water content; repeat these operations to obtain at least four couple (number of rotations; water content). Using an oven, dry every time sample to constant weight to determine water content (Table 5). Determine masses: water; dry soil (in g), then calculate water content and plasticity index using the formulas: $M_W = M_1 - M_2$; $M_S = M_2 - M_0$;

$$W = \frac{Mw}{Ms} \times 100$$

where M_W = Water mass;

M_1, M_2, M_0 = Wet weight + Tare; dry weight + Tare and Tare = Container weight M_S = mass of dry soil respectively.

$I_P = W_L - W_P$ or I_P = plasticity index.

3. Results and Interpretations

The results of the resistance bricks at the compressive are in Table 1; the recognition of some visual appreciation characteristics and the percentage of each element in the jar are in Tables 2 and 3. Physico-chemicals and particle size analysis results are shown in Tables 4 and 5. The granulometric curve is in Fig. 9.

This presents work has enabled us to determine the type of earth sample used by our great-grandparents in the construction of these century-old houses, with a view to its use in the BTP (public buildings and works sector). To do this, we used the Following techniques: measuring the compressive strength (Table 1), certain traditional techniques for assessing cohesion (tests: water status of the sample, Sample bowl let go on the ground, hand washing by moistening part of the soil and spreading it between the hands to obtain a soft paste, then washing the hands to observe whether it is easy to evacuate or not, removal of a soil (Removing the sample from the PVC ring) (Table 2 and Fig. 5), all of which sensory allow to make descriptive visual assessment of the sample, the Atterberg limit (Table 3), chemical and granulometric analysis (Tables 5 et 6 et Fig 8), which provide inform on the texture of the sample, were applied to the brick sample and has results that served as essential elements in the evaluation of our sample. Certain mineral elements (aluminum, ferric, calcium, magnesium and silicon oxides, as well as sulfate and chloride ions). The results obtained show a high silicon oxide content, more so than the other elements: (76.03%) SiO2; (9.02%) Fe_2O_3; and only

(3.02%) Al_2O_3; (5.30%) CaO, which are fundamental elements for cement manufacture (Table 5). However, chemical, granulometric and jar test analyses showed that the sample (raw earth brick) is a silico-clay material, with a clay content of almost 70% and with the presence of sand, gravel, silt and organic matter (Tables 4, 5 and 6) for a low plasticity index of: (PI = 8%). The compressive strength of the brick sample was also determined and which is to: 0.10 MPa (Table 1). which would be probably due lack compaction during brick manufacture.

4. Discussion

The compressive strength of bricks was measured on two brick samples. The average value of compressive strength of the bricks was found to be 0.10 MPa (Table 1). This value is clearly lower than the value indicated by Ref. [18], which commonly varies from 0.6 to 2.0 MPa, i.e., a difference of 0.5 MPa, but not far from that found by Valentin et al. [19], which used straws of size 2 cm as a stabilizer, i.e., 0.14 MPa. According to Valentin et al. [19], this value of the compressive strength of its brick sample is appreciable in the construction of mud buildings. However, the values found by Moro et al. [20] vary from 0.92 to 5.5 MPa at 4% cement added as stabilizer. All these differences would be probably due to a lack of compaction at the time of making the bricks for the best cohesion of the elements in the mud brick. The breaking forces of the two brick samples are: 89 and 92 kN; those corrected are: 3.77 and 3.90 respectively. Brick weights were 12.920 (brick 1) and 12.915 kg (brick 2) (Table 1), same values for surface area, the volume weight and volume which are: 396.75 cm^2; 1.63 g/cm^3 or (1,626 kg/m^3) and 7,935 cm^3 respectively. This value of volume weight (1,626 kg/m^3) may be one of the parameters for appreciation of the hygrothermal characteristics of bricks, which are in the range of 1,400 to 2,200 kg/m^3 [18]. Brick dimensions are: L = 34.50; l = 11.50 (brick 1) and same length as brick 1 but different width which equals: 11.78 cm. Tables 2 and 3 show the recognition of some visual characteristics features of appreciation and the percentages of each element in the jar: sand and gravel mixture with 50.02% and 59.71% clay this also confirms the predominance of clay in the sample which is in the range found by Ref. [15] which would be between 25% and more. However, Table 4 shows the analysis results obtained using EN 196-2 references and XRF. The results show that the sample (mud brick raw) is a silico-clay material with a high silicon oxide content: 76.03% SiO_2; 9.02% Fe_2O_3; 3.02% Al_2O_3 and only 5.30% of CaO which is one of the basic materials for the manufacture of cement. This CaO value found at 5.30% is clearly superior to the value found by Abdoulaye et al. [21] which is: 0.98% found in the soil of the Sonfonia mangrove in Conakry (Republic of Guinea) before stabilization with lime. But, the CaO content found shows that the sample (raw earth brick) has a low limestone content. However, fire loss, which is a parameter of indicator of the organic matter and organic carbon content of the soil, is: 10.59%. Some traces of 0.91% MgO; 0.46% SO_3^{2-}; 0.06% Cl^- and 49.99% insoluble residue were found. Table 5 and Fig. 9 show the results of granulometric analysis by sieving after washing 3 kg of samples using the sieve A. F.N.O. R. According to the results of Table 5, the percentage of passers-by was: 100% with sieves: 50 to 20.00 mm; while the refusal has begun from sieve 16.00 at sieve 0.080 mm with 0.70% and 53.10% respectively. The percentage passing being subtracted from one hundred (100), gives 99.30% at sieve 16.00 and 46.90% at sieve 0.080. Fig. 9 show the granulometric curve which allows us to classify our sample. The abscissa stands for the diameter of the particles and the ordinate the percentage of passers-by. By extrapolation, we find: between 2 mm and 60 mm on the y-axis (ordinate axis), gravel in the sample is 100%, from 0.06 mm to 2 mm; the sand is 80%; 0.002 mm to 0.06 mm the silt is 49%. It is to be specified that the 0.080 mm sieve, a cumulative mass of 1,594 g, was sand. It is to be specified that the 0.080 mm sieve, a cumulative mass of 1,594 g, was sand. Thus, we will

Table 6 Atterberg limit results with cup or plastic limit determination.

No.	Designation	Limits					
1	Number of blows (*N*)	16	21	26	31	Wp	
2	Container number	S	B	G	L	P	J
3	Weight of container + wet soil (M_1) (g)	36.00	36.13	36.48	36.39	34.46	29.08
4	Weight of container (M_2) (g)	33.68	33.89	34.18	34.11	33.33	28.09
5	Tare = Container weight (M_o)	24.79	24.96	24.66	24.20	26.80	22.42
6	Weight of water: $M_W = M_1 - M_2$ (g)	2.32	2.24	2.30	2.28	1.13	0.98
7	Weight of oven-dry soil: $M_s = M_2 - M_o$ (g)	8.89	8.93	9.52	9.92	6.52	5.67
8	Water content $W = (M_w/M_s) \times 100$ or $W = (M_1 - M_2)/(M_2 - M_o) \times 100$	26.10	25.10	24.20	23.00	17.30	17.30

say that before value, the clay part of the sample has been probably eliminated, i.e., a cumulative mass of 1,406 g. Atterberg's liquidity and plasticity limits being parameters enabling characterize the behavior of a clay as a function of its water content (*W*) has been determined (Table 6 and Fig. 10). For example, the liquidity limit is calculated by extrapolation from the equation of a straight line on a graph between 25 strokes which corresponds to the 1 cm closure of the groove on the abscissa axis and its corresponding on the ordinate axis. The value found must be rounded at nearest closest whole number. The plasticity limit, which represents the water content at which the crack of a clay sausage hand fashioned occurs when it reaches 3 cm in diameter. These values (W_L, W_P) are: 25%, and 17%; the average of the values $W_P/2$ in Table 6 respectively. Ip (Plasticity Index) which indicates in what condition the clay particles behave in a material has been determined and is: 8%. It is has been noted that, this value is close to that found by Lilites d'Attterbeg [22] (7%). According to Lilites d'Attterbeg [22], the value (7%) (Ip) corresponds to silt, which is just about or less than a clay, a type of soil that is intermediate between clay and fine sand. So, our sample of bricks is clayey but, with weak plasticity I_P = 8%.

5. Conclusion

The good moisture regulation is a very important feature for countries with tropical and humid climate. It should be pointed out that there are several methods of land identification. But in this work, we studied certain physicochemical and mechanical characteristics of samples of raw earth bricks taken in one of the century-old huts in the urban commune of Kouroussa (Republic of Guinea). To achieve this, the following technical methods were used: jar test, bowl let go, hand washing test, removing the sample from the PVC ring, assay reference (or according to the standard EN 196-2), XRF, granulometry, compressive strength test and Atterberg limits. It has been shown that the earth used for the confection of these brick samples is a silico-clay material which would have probably played an important role of natural binder in the cohesion of the elements in these bricks, with a very high silicon dioxide content (76.03%). These results also show a high insoluble residue content (49.9%). The lowest contents found were: magnesium oxide (0.91%) and sulfite ion (0.40%). The compressive strength of bricks without stabilizer is 0.10 MPa. This value is appreciable compared to the values found by Valentin et al. [19] and Moro et al. [20]. According to the granulometric analysis, Atterberg limits and plasticity index, our sample is outside of clay contains, gravel, sand and silt. According to the plasticity index, the sample is a clay soil with low plasticity (I_P = 8%). Our investigations have revealed that these bricks were made on the very site where the buildings were constructed (straw hut). However, further studies are recommended as this raw earth from the urban commune of Kouroussa could be an alternative for regulating humidity in buildings in humid regions of the Republic of Guinea.

Conflict of Interest

We, the authors, declare that there is no conflict of interest regarding the publication of this article.

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