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Physico-Chemical Studies and Improving the Strength of Earth Bricks Stabilized with Crushed Cellulose Paper: The Case of the Urban Communities of Mamou and Kouroussa

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Abstract

The aim of this study is to enhance the value of local earth materials used in the construction of certain homes in the Republic of Guinea. Thus, a trial study to improve the quality of mud bricks using paper fibers obtained by grinding and soaking in water and then drying were used as a stabilizer in the manufacture of these mud bricks from the sample of two sites Dounkiwal (DK) (in Mamou and the sample from the urban commune of Kouroussa). To do this, certain methods and means of identification were carried out, namely: geotechnical, mineralogical and chemical analyses. Sample DK from Mamou has a silty-clay geotechnical characteristic with a plasticity index Ip of 12.75%. However, mineralogical and chemical studies showed that sample Dounkiwal (DK) (Mamou) contains a high proportion of silica and iron oxides (79.63%) and Fe_2O_3 (11.85%), associated with other alkaline earth oxides and ions: CaO; MgO; SO_3^{2-}; Cl^-, *i.e.* 3.96%; 0.96%; 0.28% and 0.039% respectively. Its loss on ignition (LOI) and insoluble residues are 15.40% and 56.36%. The evaluation of the number of huts in Upper and Middle Guinea showed that the populations of these areas have been using mud bricks for several decades in the construction of dwellings. The average value found for the compressive strength of these bricks (from samples I, II and III from Kouroussa) is 0.16 MPa. This value is appreciable in the construction of mud houses.

Keywords

Centenary Hut, Mud Brick, Hut Construction, Resistance, Durability

1. Introduction

Earth has always been considered to be one of the first materials used in the construction of buildings in the world, such as the Great Wall of China, the 4 imperial cities of Morocco and the Croix-Rousse district of Lyon. Homo sapiens built in raw earth in what is now Syria 11,000 years ago [1] [2]. Examples of raw earth construction exist all over the world. Depending on the characteristics of the soil, such as its chemical and mineralogical composition, which differ from one soil to another, it has specific properties [3]. Today, there are 175 UNESCO World Heritage sites built from raw earth [2]. In the Republic of Guinea, huts were the first form of dwelling. Today, this type of dwelling can still be found in many of the country's towns and villages, particularly in large numbers in the towns of Upper and Middle Guinea. According to our surveys, this type of housing choice is not fortuitous, despite non-resistance the some to the multiples natural weather conditions in these regions, the population of these areas finds it interesting to live in a hut because of its benefits, comfortable with thermal and acoustic insulation performance through its straw roof and preventing noise from outside from invading the interior, as well as for economic reasons related to the high cost of construction materials [4] [5]. The wall architecture of these buildings is made of mud bricks, either simple or mixed with natural fibers as stabilizers (straw and other materials). The bricks are dried in the sun, the walls are painted in white clay and based on a circular layout, with a cone-shaped straw roof. The concrete floor inside is made from cow dung. However, some studies show that there are problems with the durability of these mud bricks in the construction of buildings when exposed to the elements (strong winds and heavy rain in the dry and wet seasons) [6] [7]. However, in many towns and villages in Haute and Moyenne Guinea (Republic of Guinea), buildings constructed from unbaked earth are still preferred by a quarter of the population, as shown in **Figure 1** and **Figure 2**, which show the cartography of huts still in existence in these regions of the Republic of Guinea. This is why a great deal of research is currently being carried out in this field, with a view to finding techniques for improving the manufacture of mud bricks by making them resistant to compression [7] [6]. We recently reported on a study of a mud brick without stabilizer in a century-old building in the urban commune of Kouroussa [8]. As a continuation of these studies, we are reporting, among the prefectures of Upper and Middle Guinea, the study on the mineralogical composition of the earth used in the manufacture of mud bricks at a production site Dounkiwal (DK samples I and II) in Mamou and the test to improve their mechanical resistance qualities, followed by, improving the quality of unsterilized mud bricks from the

Kouroussa sample, the mineralogical composition and strength of which have already been studied by our team (sample III) [8] by adding, as a stabilizer, cellulose paper collected and crushed for use in the construction of buildings in the Republic of Guinea, since paper is one of the most widely used materials in many sectors, despite the use of digital technology, which dominates the world today. Paper manufacture involves many processes that can contribute to environmental pollution, as it is made from plant fibers. The best way to avoid this would be to recycle paper, which accounts for 30% of most discarded waste [9]. The local materials (earth) being abundant can be reinforced with other elements such as organic and vegetable fibers as stabilizing in order to create a strong composite to make bricks able to fight certain climatic phenomena very abundant in these areas like: rain, sun, humidity and wind. This is why African researchers are working to find ways of improving the quality of these bricks. Our study involves the manufacture of bricks from earth as a raw material, using crushed papers like stabilizer, because, paper is a composite or material in itself. It is an entanglement of cellulosic plant fiber. Each fiber is composed of several microfibrils playing as a binder by agglomerating in solid mass of particles in the form of aggregates in adding to the earth for to make bricks. This will give a new material with additional properties that each element alone does not possess.

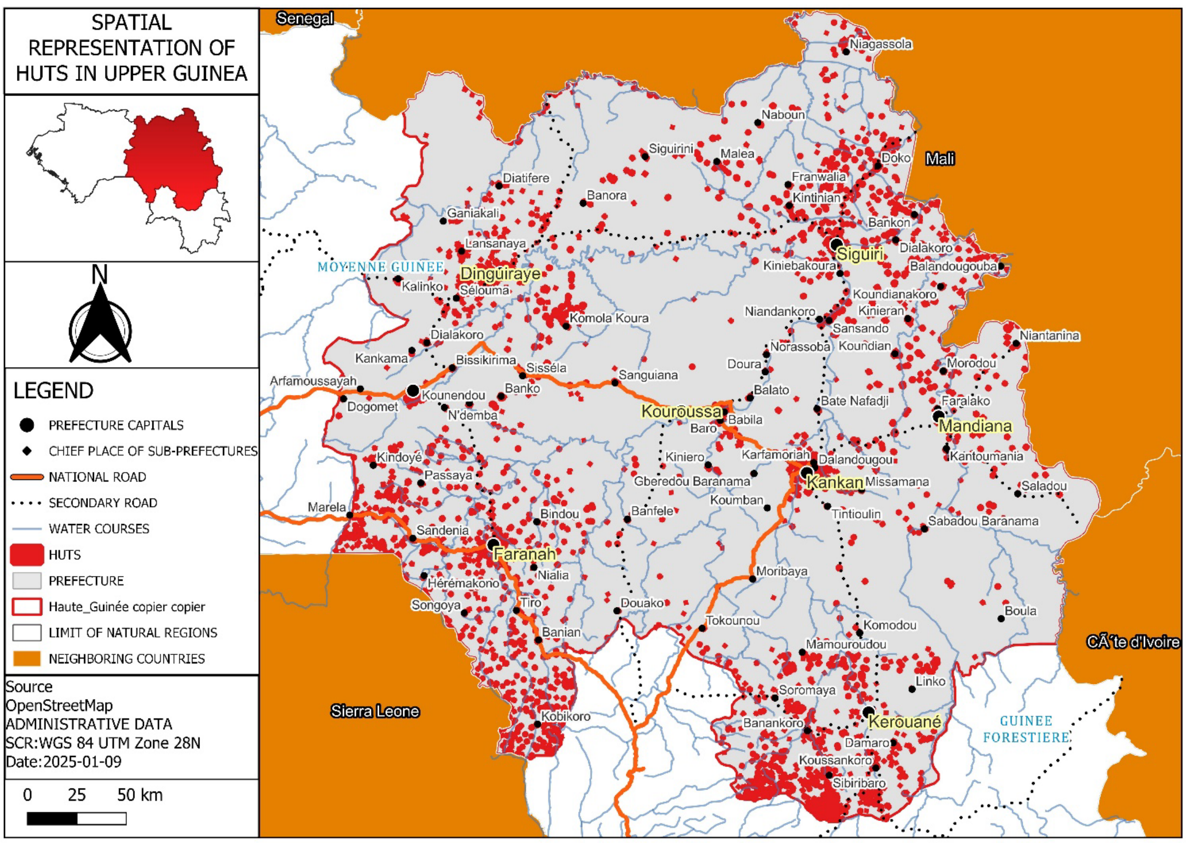


Figure 1. Map showing only mud-brick huts (straw huts) in red dots (Upper Guinea region).

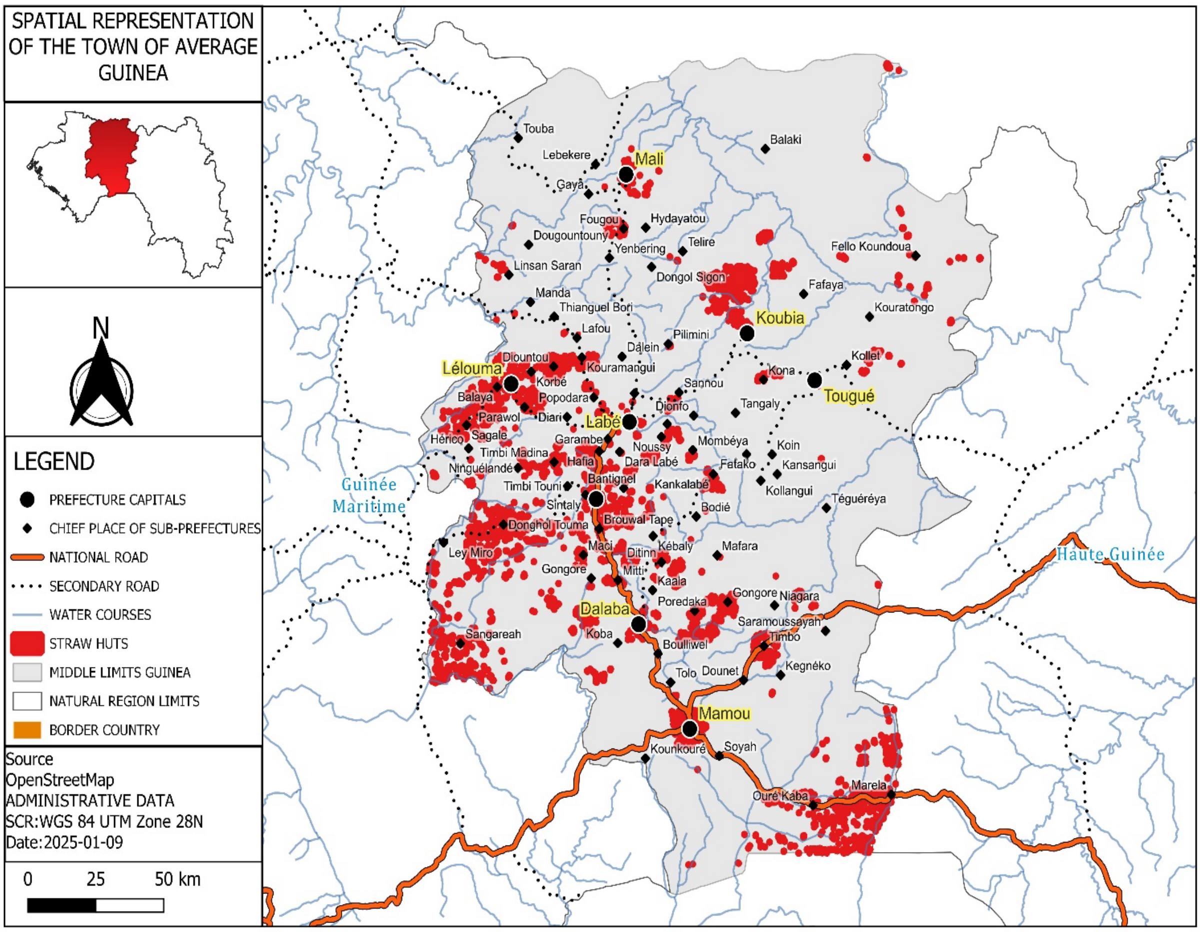


Figure 2. Map showing only mud-brick huts (straw huts) in red dots (Middle Guinea region).

2. Materials and Methods

2.1. Presentation of the Study Area

This study was carried out in the urban communes of Mamou and Kouroussa, the chief towns of Mamou and Kouroussa. They are subdivisions of the Mamou and Kankan administrative regions in Upper and Middle Guinea (Republic of Guinea). The estimated population of Mamou and Kouroussa in 2022 is 340,956 and 33,8892 respectively. Coincidentally, the two prefectures are subdivided into fourteen (14) sub-prefectures each.

2.2. Study Setting

Chemistry laboratories of the Higher Institute of Technology de Mamou, and Geotech Service (Lanbanyi Commune de Ratoma) served as the study setting.

2.3. Soil Sampling

The soil used to make the mud bricks used in this study was collected in Mamou (DK) and Kouroussa (Doula) on 25 March 2024 and served as the raw material for the physico-chemical analyses (Figure 3).

Figure 3. Examples of mud brick samples stabilized with shredded paper.

2.4. Recycling Paper Used as a Stabilizer

Paper discarded by various departments at the Mamou Higher Institute of Technology was collected and shredded using a paper shredder and soaked in a bowl filled with water for 24 hours to separate the cellulose fibers from the other materials. The slurry formed was pressed to remove water, impurities and glue, then dried and ground as shown in Figure 4 into fine particles [10].

Figure 4. Showing the cellulose fibers of recycled paper after grinding and soaking in water for 24 hours.

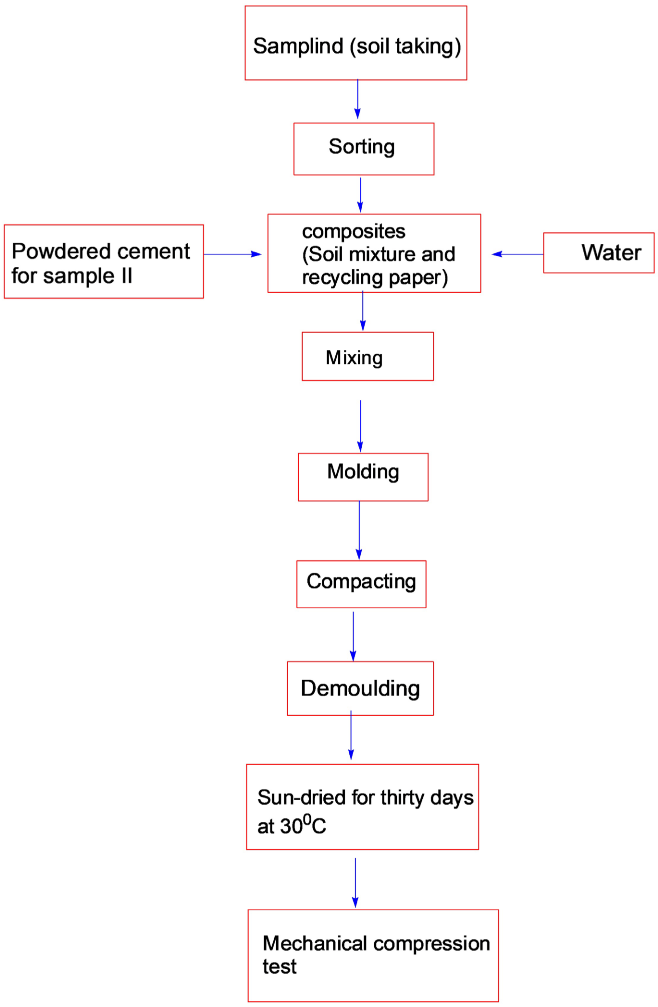
2.5. Determination of Some Mineral Elements

The chemical analysis of the brick soil samples was carried out using the wet method and in accordance with the standard: NF EN 196-2 reported in the literature [11] [12].

Chemical Products Used

The reagents: ammonium chloride, concentrated hydrochloric acid, ethanoic acid, oxalic acid and ammonium phosphate, potassium chloride and methyl red were all purchased and used without purification.

2.6. Confection of Bricks Stabilized with Recycled Paper Fiber or Cement



Scheme 1. Of fabrication of bricks stabilized with recycled paper fiber or cement.

How it works

500 g of raw earth, 150 g of fiber obtained by recycling paper and water were mixed to obtain a plastic paste. Then pour this paste into iron or wooden moulds. Compact the paste in the mould for 5 minutes and then remove from the mould, the brick is formed.

2.7. Confection of Bricks Stabilized with Recycled Paper Fibers and Cement

Manufacturing process for bricks I and III

1000 g of raw earth, 500 g of fiber obtained by recycling paper (brick samples I and III), and water all mixed together to obtain a plastic paste. Then pour the paste into iron or wooden moulds. Compact the paste for 5 minutes, then remove the mould. Then, sun-dried for thirty days at 30˚C. This compacting was carried out with the DEKLERCK-BEXE manual raw earth brick press machine.

- *Procedure for Makung brick II*

Same process but different from the first, 50 g of cement (sample II) was added to the mixture of 1000 g of raw earth, 500 g of fiber obtained by recycling paper and water.

2.8. Determination of the Number of Huts in Upper and Middle Guinea

We used QGIS (Quantum Geographic Information System) software to count the number of huts.

2.9. Granulometric Analysis

Granulometric techniques using the sieving method were carried out using a column of square mesh sieves with successive different openings from top to bottom, and a basket for washing the sample [9].

2.10. Atterberg Limits According to NF P 94-051

The Atterberg Limits (commonly used with a cup) to determine the geotechnical properties of the sample used in this study and taking into account certain parameters (liquidity limits $\mathbf{W_L}$; plasticity limits $\mathbf{W_P}$) and the plasticity index $\mathbf{I_P}$, according to standard NF EN ISO 17892-12 [12] [13]. The values found are shown in **Table 1** and **Figure 5**.

Equipment Used

The Casagrande apparatus, which is fitted with a cup, smooth stroke counter, weighing base, guidance and adjustment mechanism, balance and groove tool), numbered and tared N, L, H, C, R and T plates (**Table 1**) [9].

2.11. Measuring the Compressive Strength of Raw Brick

Compression tests were carried out on three samples of raw brick according to the following procedure and previous work [8]. Placed the raw earth brick without coating or lateral support between the trays frame of a machine with mechanical load. The bricks were previously well cut so that the contact is good. The values of the load and the deformation are marked immediately after the rupture, The resistance in MPa was found using the formula:

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

Or: BF = breaking force

PC = press correction (0.0424)

S = brick surface

3. Results and Discussion

The results: chemical composition (moisture content of mineral elements), number and percentage of boxes per prefecture in Upper and Middle Guinea (Republic of Guinea), grain size, Atterberg limits with cup, compressive strength of the bricks are shown in Tables 1-4 and Figures 5-7. The results of the compressive strength of the bricks are in (Table 5). The grading curve in Figure 8.

Table 1. Chemical composition (wet process) with code NF EN 196-2 of the sample: DK 2.

Elements	Symbol	Content (%)	Test reference (or according to the standard)
Loss on ignition	paf	15.40	EN 196-2
Insoluble residue	Rins	56.36	EN 192-2
Silica oxide	SiO_2	79.63	EN 196-2
Alumina oxide	Al_2O_3	2.96	EN 196-2
Ferric oxide	Fe_2O_3	11.85	EN 196-2
Calcium oxide	CaO	3.96	EN 196-2
Magnesium oxide	MgO	0.963	EN 196-2
Sulphite ion	SO_3^{2-}	0.28	EN 196-2
Chloride ion	Cl^-	0.039	EN 196-2

Table 2. Number of huts per prefecture in Upper Guinea.

Prefecture	Number of Case
Dinguiraye	57033
Siguiri	44432 mining area, but more huts in the sub-prefectures and villages
Dabola	10504 And the center of Guinea
Faranah	85986
Kouroussa	22097 mining area
Kankan	26453 2nd largest city in Guinea
Mandiana	73612 mining area
Kérouane	2822 cultural mix

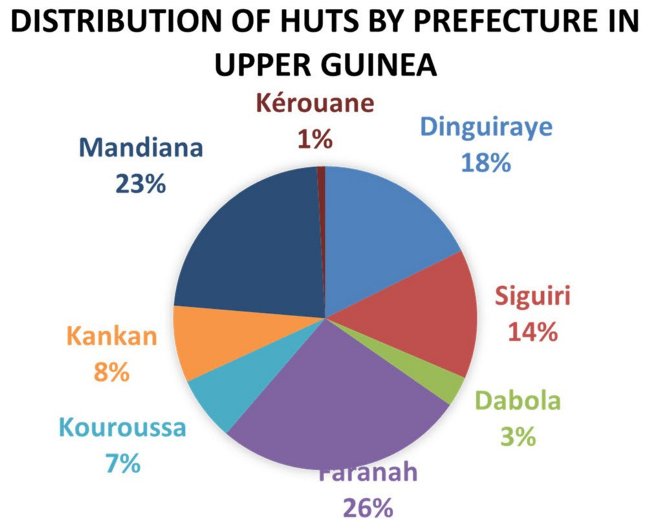


Figure 5. Percentage of boxes for each prefecture of Upper Guinea.

Table 3. Number of huts per prefecture in Middle Guinea.

Prefecture	Number
Mamou	13657
Dalaba	4851
Pita	17306
Labé	4180
Lélouma	8551
Mali	2158
Koubia	8342
Tougué	3767

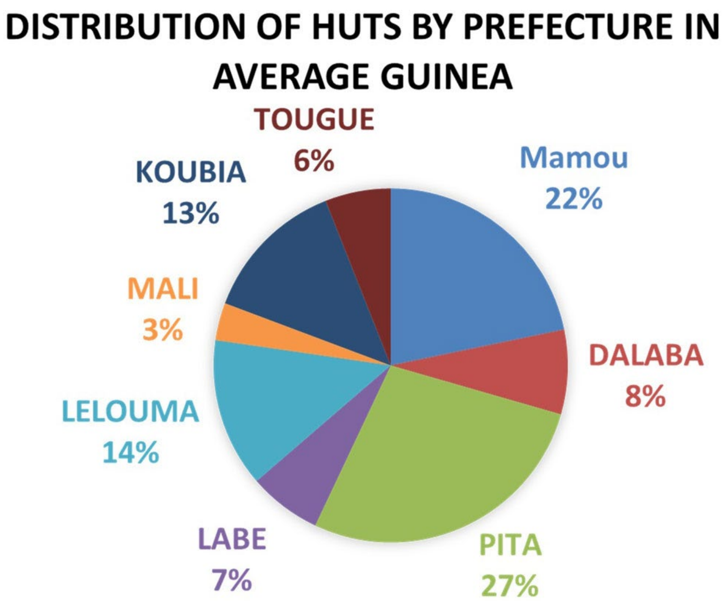


Figure 6. Showing the percentage of boxes for each prefecture in the Guinea average.

Table 4. Results of Atterberg limits with cup (Limits of liquidity and plasticity).

N⁰	Designation	Limits (liquidity limit)					
1	Number of strokes (N)	15	20	25	30	Wp (plasticity limit)	
2	Container number (plates)	N	L	H	C	R	T
3	Wet weight + Tare (M1) (g)	37.80	35.46	33.74	31.34	33.80	32.44
4	Dry weight + Tare (M2) (g)	33.82	32.14	30.90	28.61	31.39	30.34
5	Tare = Weight of container (Mo)	24.58	24.23	24.04	21.89	22.99	23.11
6	Mass of water: MW = M1 − M2 (g)	3.98	3.32	2.84	2.72	2.42	2.10
7	Mass of dry soil: Ms = M2 − Mo (g)	9.24	7.91	6.86	6.73	8.40	7.23
8	Water content W = Mw/Ms × 100 or W = M1 − M2/M2 − Mo × 100	43.07	41.97	41.40	40.28	28.81	29.05
Average water content Limits liquidity and plasticity (%)		41.68				28.93	

Table 5. Results of the plasticity index.

Liquidity limit	41.67
Plasticity limit	28.93
Plasticity index (PI = LL − LP)	12.75

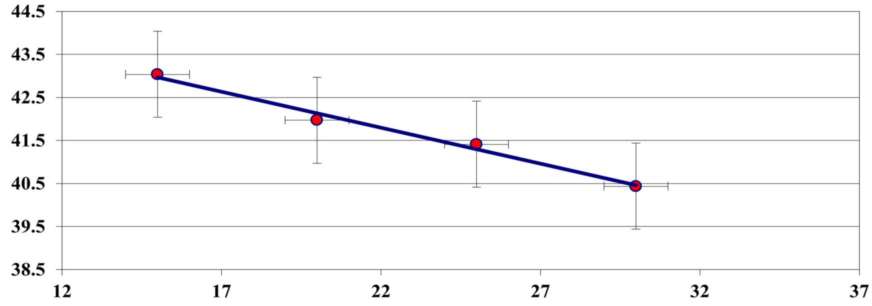


Figure 7. Representation of the pairs of values with the water content on the ordinate and the number of rotations or blows producing closure of the slit on the abscissa.

Table 6. Results of particle size analysis by sieving after washing 3 kg of samples with Sieve A. F.N.O. R.

Module	Opening (mm)	Cumulative weight (g)	% Rejects	% Passages
Block	50	0.00	-	100.00
	40	0.00	-	100.00
	31.50	0.00	-	100.00
	25.00	19.2	0.60	99,40
	20.00	37	-	100.00
Gravel	16.00	48	1.60	98.40
	12.50	87.30	2.90	97.10
	10.00	129.60	4.30	95.70
	8.00	189.60	6.30	93.70
	6.30	265.90	8.90	91.10
	5.00	352.90	11.80	88.20
	4.00	431.70	14.40	85.60
Sand	3.15	480.10	16.00	84.00
	2.00	561.30	18.70	81.30
	1.00	658.50	22.00	78.10
	0.500	763.60	25.50	74.50
	0.400	800.80	26.70	73.30
	0.315	848.80	28.30	71.70
	0.16	976.80	32.60	67.40
	0.080	1078.60	36.00	64.00

Table 7. Brick compressive strength values.

N0 of brick samples	Length (cm)	Width (cm)	Height (cm)	Weight (g)	Surface area (cm2)	Volume (cm3)	Density	Breaking force (KN)	Cor-rected breaking force 0.0424 (KN)	Resistance (MPa)
I	35.6	19	13.20	12096	676.4	8928.48	1.35	254	10.77	0.16
II	35.6	19	13.20	13218	676.4	8928.48	1.48	236	10.01	0.16
III	35.6	19	13.20	18291	676.4	8928.48	2.05	262	11.11	0.16
Average (MPa)					0.16					

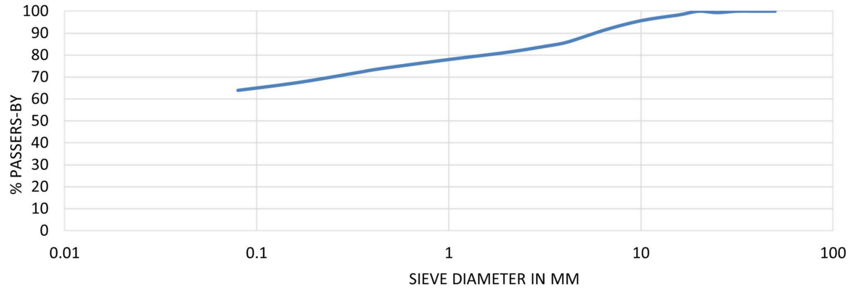


Figure 8. Sieve size curve 4. Discussion.

The analysis results in **Table 1** show that the lateritic soil used in this experiment, after evaporation of the volatile species in the sample, which corresponds to a loss of mass (loss on ignition), gave a loss on ignition value of: 15.40 %. The sample consists mainly of silica oxide (79.63%) and Fe_2O_3 (11.85%), combined with other metal oxides and ions such as: Al_2O_3 (2.96%); CaO (3.96%); MgO (0.963%); SO_3^{2-} (0.28%); Cl^- (0.039%) respectively. These oxides are cations (positive ions), which ensure the electrical neutrality of the mineral [14]. These results show that the sample is a silt-clay material [15]. With the exception of the aluminum oxides Al_2O_3 and CaO, these values are higher than those found in our previous study on the Kouroussa brick sample [9], which are: (76.03%) SiO_2; (9.02%); Fe_2O_3 (9.02%) and those found by [7], which are also: (42.96%) SiO_2; (6.44%) Fe_2O_3; (31.50%) Al_2O_3 and (2.69%) CaO. However, other elements such as magnesium oxide and sulphate and chloride ions (MgO, SO_3^{2-}, Cl^-) are only present in trace form. However, the loss on ignition (LOI), which is a parameter that indicates the organic matter rate and the organic carbon content of the soil, is: 15.40%. This value is higher than those found in our previous study on sample III of **Table 1**, which was 10.59% [8], and that of [12], which was 14.91%. According to [12], the increase in water content and other volatile organic matter after calcination is probably due to poor drying of the samples and the very fine particle size of the sample, between 2 μ and 2 mm, with the creation of a specific surface which causes capillary retention. **Tables 2 and 3** and **Figures 5 and 6** show the number of huts per prefecture in Upper and Middle Guinea, with high percentages of 26% in Faranah, followed by 23% in Mandiana. The lowest percentages are in Kérouané and Dabola, at 1% and 3% respectively in Upper Guinea. In Middle Guinea, the highest percentage is in Pita (27%), followed by Mamou (22%). The percentage is low in Mali Guinée (3%), followed by Tougué (6%). The two regional capitals of these prefectures (Kankan in Upper Guinea and Labé in Middle Guinea) are at: 8% and 7% respectively. **Tables 4, 5** and **Figure 7** show the results of the Atterberg limits with cup (liquidity and plasticity limits), the plasticity index and the representation of the pairs of values with the water content on the ordinate and the number of rotations or blows producing closure of the crack on the abscissa. The mean values (WL, WP and Ip) are 41.68%, 28.93% and 12.75% respectively. According to [15] and [16], a silt-clay soil has the following components: clay (28% - 40%); silt (15% - 52%) and sand (20% - 45%) with an average plasticity index (Ip) of: 10% - 20%. The Mamou soil sample used to make these bricks, which falls within this range, is silt-clay. At the same time, the compressive strength of the bricks was measured on samples from Mamou and Kouroussa (samples I, II from Mamou and III from Kouroussa). **Table 6** and **Figure 8** show the results of the granulometric analyses of the soil, which was split into granular groups of decreasing size obtained by wet sieving after washing 3 kg of samples using the sieve proposed by standard NF XP 13-901 on CEB (A. F.N.O. R) [17] [18]. According to the results in **Table 6**, the number of 100% passes was obtained with 50 to 31.50 mm sieves, higher than that of sample III obtained in our previous study, which was 50 to 20.00 mm [8]. However, a refusal of 0.60% was noted at the 25.00 sieve, which may probably be due to the size of certain aggregates that were poorly dried at the time of drying after washing. Real refusal starting from sieve 16.00 to sieve 0.080 respectively. After weighing, the cumulative mass values vary from 19.20 g (25 mm; and block) to 1078.60 g (0.080 mm; sand). **Figure 8** shows the particle size distribution curve used to classify the particles in the sample. According to [19], the interpretation of a curve is limited by extrapolation between the abscissa and ordinate axes. When the diameter of the particles is less than 0.002 the soil is clayey, between 0.002 and 0.06 silt, 0.06 to 2 sand and 2 to 60 mm gravel. So, if we look at the curve, we have: 100% gravel, 80% sand; silt is 61%. We can therefore say that the clay, silt, impurities, limestone, plant debris and organic matter contained in the sample were eliminated when the sample was washed and dried in an oven before particle size analysis. The particle size distribution (**Figure 8**) shows a sort of two particle size classes with a stretched, irregular shape, with a series of ranges starting with medium grains and ending with coarse grains (a mixture of coarse, medium and fine grains). The compressive strength of the bricks found to give an average value of 0.16 MPa (**Table 7**). This value would be lower than that reported by [18] which states that the best value of compressive strength is between 0.6 and 2.0 MP. However, the value found in this study is higher than that found by [19] which is 0.14 MPa with straw as stabilizer. According to him, the 0.14 MPa value found is appreciable in the construction of raw earth buildings [7]. In the sample of Dounkiwal (DK), the content of Fe_2O_3 is at (11.85%). This value is appreciable because it is at a difference of 0.135% from that found by [6] in his sample de ETI which is: 13.20%. According to him, this element would be responsible for the red colouring of the bricks. This coloring is an asset for the sample because according to [20] [21], it can be a natural dye for the stabilized earth blocks and the tiles. However, the loss on ignition (LOI) of our sample (15.40%) is greater than its value in its sample ETI, which is: 13.91% [6]. This shows that the clay content of our sample (DK2) is high. Our study showed that in the soil sample (Kamboinsé in Burkina Fasso) studied by [22], the SiO_2 value found would be (50%) lower than that found in our DK2 sample which is a: 79.63%. He is one of the most important and abundant oxidants on earth, because accounting 60% of the weight of the earth crust [23]. According to [24], the plasticity index and liquidity limit are among the criteria for assessing the plasticity of a clay.

Compared to these results, our liquidity limit of 41.67% would be close to its liquidity limit value of (55.2%).

4. Conclusion

In this work, experimental studies were carried out and enabled us to carry out tests and obtain three samples of acceptable raw earth bricks stabilized by previously ground paper fibers (two of Dounkiwal or DK in the Mamou prefecture) and one in the Kouroussa prefecture. Before and after the production of these control bricks, we determined certain physico-chemical characteristics of the earth samples (DK) in the urban commune of Mamou (Republic of Guinea), and measured their mechanical strengths. To do this, we found that the raw earth material from Dounkiwal (DK Mamou) has a silty-clayey earth characteristic and consists mainly of silica and iron oxides with, (79.63%) and Fe_2O_3 (11.85%), associated with other metal oxides and ions. Its loss on ignition (LOI), which is a parameter indicating the level of organic matter, is 15.40%. However, an assessment of the number of huts per prefecture in Upper and Middle Guinea shows that people in these areas still use mud houses for their homes. Experiments have shown that the value found for the compressive strength of these bricks (0.16 MPa) is appreciable in the construction of raw earth buildings. The exception would be despite the mixture of raw earth, recycled paper fibers and a quantity of cement powder and water used to make the brick (sample II), the compressive strength value is still the same. The prospects in this study would be to find a better stabilization up to the normal value indicated in the literature. Sample DK from Mamou is a mixture of coarse, medium and fine grains, according to the results of the particle size analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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