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Rediscovering the Ancient Cob Wall of Madagascar for Potential Green and Economical Construction

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Abstract - *Earthen constructions have existed for thousands of years in the world. In Madagascar, remains of over 300 years of construction still exist today and are part of the « Malagasy » heritage. Currently, the construction methodology and the know-how around the constructions with cob are almost in-existent. The purpose of this research is not only to find the techniques to rebuild with raw earth and to reduce the carbon footprint in civil engineering in Madagascar, but also to provide an economic alternative to concrete constructions. Various samples have been taken and analyzed to determine the formulation of the « Malagasy » cob and to demystify the misleading idea that these types of constructions contain additives of animal origin. Building with earth will definitely reduce cost and maintain sustainability, and once the right composition is determined, it will be possible to provide various architectural designs with a life span of 50 to 100 years, depending on implementation techniques used. Finally, this will lead to the use of abundantly available material locally, hence reduce additional transportation and related costs, yielding recyclable and economical structures.*

Currently, the ancient construction cultures and eventually, the know-how around the constructions of are practically unknown. The aim of this research is not only to find the techniques to rebuild with raw earth and to reduce the carbon footprint in civil engineering in Madagascar, but also to provide an economic alternative to concrete for the majority of the population. Various samples were taken and analysed to determine the formulation of the "Malagasy" cob and to demystify the type of construction with regard to the use of spurious additives of animal origin.

Keywords: cob wall, carbon footprint, concrete, sustainable, green construction.

1. Introduction

Building materials in general include all components used in the field of civil engineering for construction purposes. Because of its abundance and accessibility in terms of cost, the earth material is the most used one, worldwide, Steve, 1997 [1].

Constructions with mud are among the oldest that our planet has known, Fabien Ginisty 2018 [2] Hamard E, Cazacliu B, Razakamanantsoa A, Morel J-C [9]. Their appearance in Madagascar cannot be dated with precision, but we find in historical documents from the era of King Andrianampoinimerina (1745-1810) who banned in his royal edict, constructions in cob or stone for people who are still alive. There are many types of mud constructions in Madagascar and these include adobe construction. The latter is undoubtedly the most affordable and surpasses by far other techniques for many reasons. This is evidenced by the remains of the past through the old buildings. Few mud or adobe

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constructions have survived the centuries to find themselves still intact today.

Oral traditions would indicate the presence of ovalbumin, cow dung or sap in the old cob constructions, but we will retain only the main constituent materials which are the earth and the plant fibers used to limit the cracks due to swelling and shrinkage. The ease of construction, combined with the ease of design have made the cob-wall, as a preferred one, as compared to other techniques of construction with mud. It is a traditional technique that has been used for thousands of years and in all kinds of climates, Greer and Short, 1995, [3]. These buildings are also known to be very weather-resistant because of their porous nature that can withstand long periods of rain without losing its main properties, Keefe et al., 2001 [4].

Unfortunately, the formulation of the cob has not been transmitted to current generations and the ancestral know-how for its implementation have also been lost. This is again evidenced by the visible constructions that still stand in excellent conditions.

To rediscover the old formulation, we will need to analyze different types of cob-wall, but also other standard soils for comparison.

This study focuses on the cob-wall in the highlands of Madagascar (the central part) whose altitude is above 800 m. The main objective of this study is to present physicochemical results and the mineralogical characterization of cob-wall and soils, with the specific objective of rediscovering it, and the demystification of the use of the various stabilizers and waterproofing agents of the time.

2. Materials and methods

The raw materials were sampled cob from the sites:

1- The residence of King Radama located in Manandrina, Antananarivo Avaradrano (GPS coordinates : Altitude 1316 m, Latitude S 18 ° 48'37,40 '' Longitude E 47 ° 35'24,14 '').

2- An old wall in Antanety, Antananarivo Atsimondrano (GPS coordinates : Altitude 1266 m, Latitude S 18 ° 55'52.97 '' Longitude E 47 ° 29'01.25 '')

Figure 1a. Cob-wall Radama, Manandriana Antananarivo (150 years old – photo by author))

Figure 1b. Cob-wall Tana (Antanety – photo by author)

The remaining soil samples were taken from:

1- A deposit located near Moramanga, (GPS coordinates: Altitude 878 m; Latitude S 15°52'11.20"; Longitude E 48°05'15.77")

2- An adobe deposit located near Antsirabe (GPS coordinates: Altitude 1488 m; Latitude S 19°50'02.12"; Longitude E 47°02'54.59")

These samples-cob were analyzed for their clay mineralogy (Chamayou and Legros, 1989; Brindley and Brown, 1980; Tan, 1991) [5]. The mineralogical composition was obtained from the X-ray diffraction (Bruker D8 advance diffractometer using CuKa1 radiation (λ = 1.54056)) on powders obtained by grinding the original of cob or soils samples, then sieved at 40 microns for strips with fraction less than 40 microns (obtained by degressive sieving, to remove the quartz) treated with ethylene glycol. These methodology will also allow to determine the existence of swelling clays.

Thermogravimetric (ATG) and thermodifferential (ATD) analysis of the soil samples were realised using the mettler toledo TGA2.

The porosity of the solid samples was measured using a micromeritics autopore IV, mercury porometer with a low-pressure cycle (0.0037 MPa) and a high-pressure cycle (0.0007 ~ 413 MPa).

Particle size distribution as well as the plasticity of these building materials were also determined.

3. Results and discussions

3.1 X-ray diffraction analysis

Each clay family is characterized by a value of "d" of the plane (001). The main reflections d (001) = 26.5 Å; d (001) = 12 Å; d (001) = 8 Å; d (001) = 27.7 Å and d (001) = 18 Å in Figure 2 indicate the presence of quartz, kaolinite, illite, feldspar and gibbsite, respectively, Brindley and Brown, 1980; Eslinger and Peaver, 1988, [6] in the sample

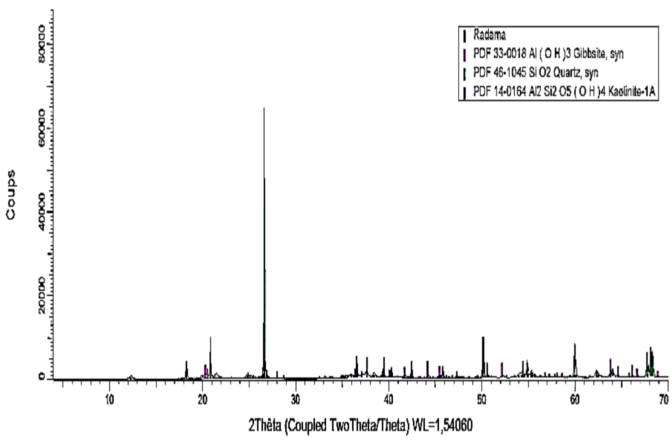

Figure 2. Cob-wall Radama is characterized by the value of "d" of the plane (001)

The results indicate that Radama and Antanety's samples have the same composition despite their age difference of about 3 centuries. The intensities of the peaks are somehow different, indicating different concentrations of minerals, but the composition is the same. The soils used for earth construction in ancient Madagascar are ordinary lateritic soils of the highlands.

The results of the XRD are distorted because of the "hyper-refraction" of quartz. Thus the withdrawal the refraction curves and flattening the values of the weakly refractory minerals. But here, the study focuses on the different types of clays and for this purpose the quartz minerals had to be withdrawn from the other minerals. Screening at 40 µm eliminates quartz minerals and focuses on the 2 Å to 40 Å portion. The sieving result is first X-rayed, then it is treated with ethylene glycol, and again x-rayed. This process will eventually confirm the presence or absence of swelling clays. Figures 3 and 4 below, show the results of the X-ray diffractions on the samples under investigation.

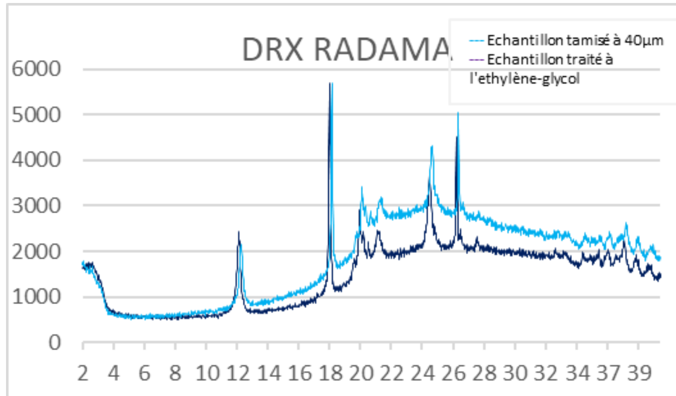

Figure 3. Diffractogram of cob Radama

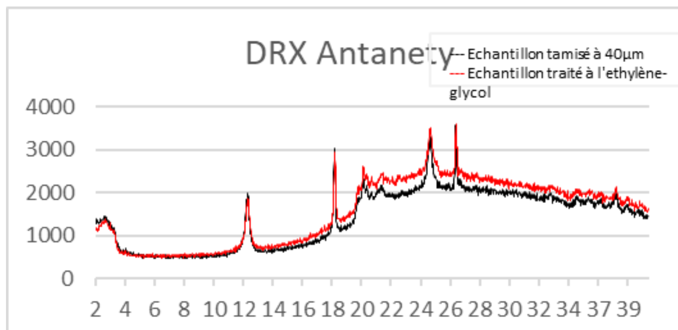

Figure 4. Diffractogram of cob Antanety

In figure 3 and figure 4, the peak at 12.37 Å and the absence of a peak around 7Å on the diffractogram of the clay fraction indicate the presence of kaolinite. This clay is not swelling because the treatment with ethylene glycol does not show a migration of peaks to the left. This partly explains the extreme durability of the earth constructions in Madagascar.

3.2 Thermogravimetric analyzes of the cob

Furthermore, two types of thermal analyses were performed on the above samples: differential thermal analysis (DTA) and thermogravimetric analysis (TGA).

The purpose of the DTA is to evaluate the energy released or absorbed by the material when it undergoes physical or chemical transformations during a thermal cycle; the TGA measures the mass variation of a sample during a thermal cycle.

This again partly explains the extreme durability of the constructions in Madagascar.

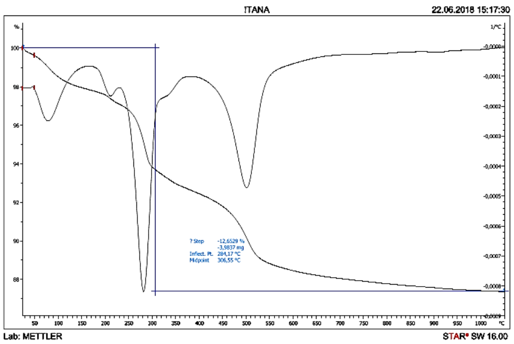

Figure 5. Diagrams of the thermal analysis curves of the "TANA-Antanety"cob

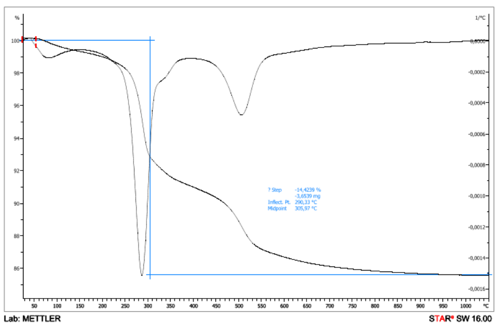

Figure 6. Diagrams of the thermal analysis curves of the "Radama" cob

The thermal analyzes of the two samples indicate that the samples taken, have almost identical characteristics. The shape of the DTA and TGA curves in figures 5 and 6 above is typical compared to those obtained with materials containing clay minerals.

Three weight loss events are observed in the TGA and DTA curves at 60-70ºC, 250-300ºC and 500-520ºC, with total weight loss ranging from 12.65% to 14.43%.

According to the DTA curves shown in figures 5 and 6 above, the first endothermic peak is linked with the evolution of water, physically adsorbed by the kaolinite particles. The second weight loss is due to the evolution of water resulting from the dehydration of the gibbsite and its subsequent transformation into an alumina transition phase.

The third weight loss is mainly associated with the dehydroxylation of kaolinite, which is transformed into metakaolinite. A large exothermic peak around 350 ° C, due to the decomposition of organic matter, was observed for all the samples analysed. In the present case, the weight loss in the temperature range of 250 to 300 ºC is considered to be due to the dehydration of gibbsite, G. P. Souza, 2005 [7], whereas that in the range of 400 to 600 ºC is due to the dehydroxylation of clay components.

3.3 Cob Porosity

The sample of the cob soaked in water shows the appearance of air bubbles driven out by the water (figure n°7); thus, the cobs are porous materials and this characteristic is determined by the porometric test whose results are summarized in table n° 1. According to the results, the porosity of the gauges is of the order of 34 to 36 percent which corresponds to the average value of gauges in the world which is 30 to 40 percent, Keefe L, (2005) [4] . The various pore diameters are illustrated in Figures 8 and 9.

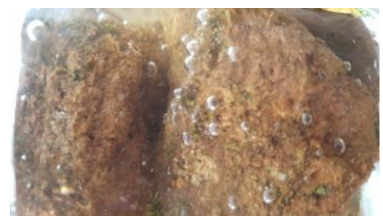

Figure 7. Cob soaked in water, the presence of bubbles shows the porosity (photo by author)

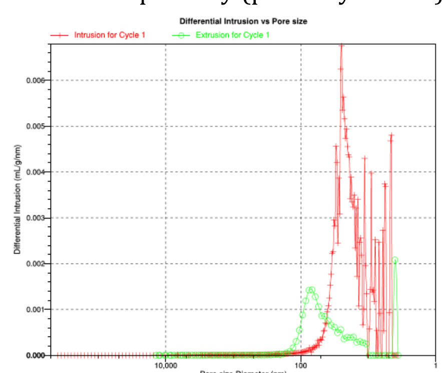

Figure 8. Radama cob porometer test

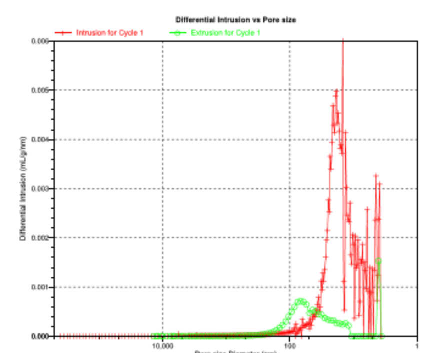

Figure 9. Tana cob porometer test

Table 1. Porosity of the cob

Sample	Porosity [%]	Average porosity per site [%] Sample
Radama 1 Cob	35,56	
Radama 2 Cob	35,88	35,72
Tana 1 Cob	33,63	
Tana 2 Cob	35,16	34,39

3.4 Particle Size Analysis and Plasticity

The results of the laser sizing tests (Fig.10) indicate that the Radama and Tana cob samples have the same distribution of soil grains in terms of diameter and percentage despite their difference in age and sampling site. These results are also confirmed by sieve size tests, wet sieving (Fig. 11). The curves take the form of spread grain sizes.

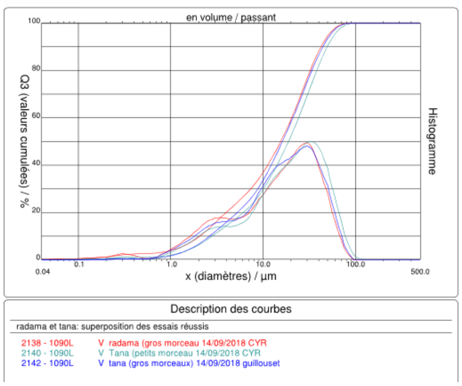

Figure 10. Particle size curves, by laser, of the Radama and Tana cob samples

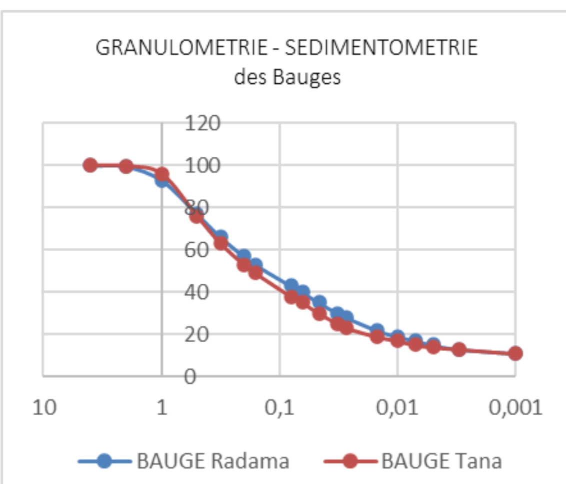

Figure 11. Sieve size curve, wet sieving, of the Radama and Tana cob samples

As far as plasticity is concerned, the various states of the soil correspond to humidity ranges separated by characteristic water contents known as Atterberg limits:

- the W_l liquidity limit,
- the limit of plasticity W_p.

The important parameter here is the liquid limit which predicts the plasticity of the material, a characteristic of the soil that is indispensable for the manufacture of the cob.

Based on these two parameters, one can define what is expected by the plasticity index (I_p) of the soil by the following formula.

$$I_p = W_l - W_p \qquad (1)$$

During the determination of the Atterberg Limits test, samples from the Radama cob did not settle easily even after seven days of washing, whereas a sample of new soil settled only in two hours after washing (Fig 12a and 12b). This shows the good cohesion of the particles forming the cob.

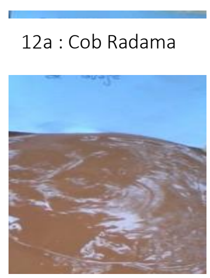

Figure 12 (a)

Figure 12(b)

Figure 12. (a) and (b) - Aspect of the settling of the cob and the natural soil (photos by author)

Table 2, below, summarizes the physical characteristics of the cob. It is concluded that the cobs have a liquidity limit equal to thirty percent, they are plastic materials and they contain a percentage of fines higher than 45 percent; results confirmed in the literature [9] [10].

Table 2: Physical characteristics of the cob

N°	Sample	WL	WP	Gamma D [kN/m3]	% fines [%]
1	RADAMA cob	**30.8**	21.6	16.6	**47**
2	TANA cob	**31.1**	19.5	15.7	**46**

4. Conclusion

Cross-referencing of the different test results is necessary to identify the malagasy material cob: the diffractogram, the thermogravimetry, the granulometry, the plasticity and the porometry.

The samples consist of fine porous plastic materials containing non-swelling silt and clay minerals, as well as organic materials. This characterization is one of the important and essential tools necessary for construction using earth. Indeed, it is a durable material, non-toxic, easy to use, ecological and very economical, Laurence Keefe 2005 [8], Myriam Olivier 2016 [10].

In future, this research should aim at the optimization in the implementation process and improvement of the characteristics of the cob in Madagascar.

References

[1] Steve, B., Cob and Straw Bale Construction: The Perfect Marriage. Programme for Sustainable Living Fair, Montrose CA. (1997).

[2] Fabien Ginisty, Terre crue, l'autonomie sous nos pieds, dossiers l'âge de faire (2018)

[3] Greer, M. and D. Short, Aspect of the Composite Behaviour of Cob. A Seminar Paper on Out of Earth
II. University of Plymouth, England. (1995).

[4] Keefe, L., L. Watson and R.A. Griffiths, A proposed diagnostic survey procedure for cob walls. Inst. Civil Engin. Struct. Build., 146: 57-65. (2001).

[5] Chamayou and Legros, 1989; Brindley and Brown, 1980; Tan1991, Les bases physiques, chimiques et minéralogiques de la science du sol. Presses Universitaires de France, Paris.

[6] Brindley and Brown, 1980; Eslinger and Peaver, Clay minerals for petroleum geologists and engineers, SEPM Short course 22. Soc. Economic paleontologists and mineralogists, Tulsa, USA (1988)

[7] G. P. Souza, S. J. G. Sousa, L. A. H. Terrones, J. N. F. Holanda , Mineralogical analysis of Brazilian ceramic sedimentary clays used in red ceramic (2005)

[8] Laurence Keefe, Earth Building: Methods and Materials, Repair and Conservation, (2005)

[9] Hamard E, Cazacliu B, Razakamanantsoa A, Morel J-C, Cob, A vernacular earth construction process in the context of modern sustainable building, Building and Environment (2016)

[10] Myriam Olivier (CEREMA), Ali Mesbah (ENTPE). Introduction à la construction en terre Document préparatoire au séminaire-formation " Construire en terre crue de Guyane" Organisé par la DEAL Guyane (2016)