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Study of the Stabilization of the Laterite by Microorganisms Activated By Manure, Sugar And Urea

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***Abstract**: Stabilization is a method appropriated to the physic and chemical constraints to improve the mechanical property of a material. To stabilize means to modify the initial properties of a system soil-water-air, the soil has other interesting and compatible properties to a modification to get compatible permanent structures for an application. It is about the mechanical, physical and chemical stabilization. Three ways possible exist to consolidate the soil. These three processes can be applied, alone or in general, coupled. Several works of research on the stabilization of the laterite have been done. They already gave satisfactory results on the improvement of the mechanical strength with the chemical stabilizers as the cement and the lime. Unfortunately, this mode of stabilization requires an expensive technique and also provokes ominous effects on the environmental plan by the emission of gas to greenhouse effect because the preparation of these binders requires a cooking to high temperature. Tests of stabilization by the polymers have also been done. They gave satisfactory results. However, the expensive cost of the stabilizer makes this technique costly. The stabilization of the laterite by microbes gave a result satisfactory in the field of mechanical strength, porosity and manufacturing cost. Indeed the materials gotten from the tests done in the setting of this work have the technical properties that could compete those gotten from the chemical stabilization.*

***Keys words**: laterite, biotechnology, microbial reduction of iron, granulometric improvement.*

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I. Introduction

For years, the Malagasy constructed their works from natural materials, and after evolution, they practiced traditional methods to manufacture the construction supplies of which some remain again on the market of today as the bricks in raw earth, the bricks and tiles made of terracotta. The walls in earth raw, named " Tamboho " that subsists again in the peripheral zones of Antananarivo, after several decades of existence are part of these works.

In excellent Madagascar, the use of the laterite soil, an abundant natural resource on the territory, offers an alternative for facing the lacks of construction supplies or the too elevated prices of these products. However, the mediocre mechanical qualities of this material used that in the constructions little solicited mechanically.

To develop the constructional policy in Madagascar, the valorization of the laterites as constructional material in the domain of habitat (foundation, base, wall, pillar) and road (base layer and foundation) is a necessity.

Several research works have already given satisfactory results in the improvement of the mechanical resistance and the reduction of the sensibility to the effect of water on materials made of laterites. The chemical stabilization (by the cement, the lime, the polymers…) of the laterite is part of these works. However, the manufacturing cost of the material gotten with this technology is high, because the price of the stabilizer that is still expensive currently must be added to it.

A binder based on oxide of iron and active silica has been elaborated by RANDRIANA and other people in 2004. However, the gotten mechanical strength is not satisfactory in relation to the products consolidated above stated.

Thus, we propose in the setting of this work, the stabilization of the laterite the micro-organisms. This process is at a time modern and less dear, because micro-organisms substitute the chemical products. The process is simple. It only requires simple materials.

II. Material And Methods

The geotechnical characterization of the latérite has been done in the National Laboratory of the Public works and Buildings (LNTPB) situated in Antananarivo. The material used includes :

- a dry off oven ;
- a precision scales ;
- diverse glasswares;
- a set of screens ;
- a Casagrande device ;
- a mold and a Proctor rammer.

The chemical constituent of the laterite have been determined by spectrometry in X fluorescence in the laboratory of the Holcim cement factory located in Ibity, Antsirabe. The mineralogical composition has been determined by diffraction of X-rays (DRX).

The equipments used for the study of the process of stabilization of the laterite by microorganisms are constituted of :

- bioreactors made from plastic cans ;
- mold for the preparation of test ;
- multifunctional hydraulic press of the technical Block of the polytechnic college of Antananarivo (ESPA), used for the milling and the determination of the mechanical resistance ,
- analytical balance for the determination of the porosity.

The methodology of stabilization consists in reducing the Fe^{3+} ion in Fe^{2+} in anaerobic, with or without grading correction. Fe^{2+} thus obtained, which is very unstable, oxidizes in the presence of the oxygen of the air during the drying.

III. Place Of Taking Collection Of The Sample Of Laterite

The laterites which we used, within the framework of this work, were collected in two different zones:

The first has been taken at 1 km in the southwest of the Academic Campus of the Polytechnic College, that we call " laterite 1 » ;

The second has been collected within the Polytechnic College Academic Campus, that we designate by " laterite 2 ."

The geographical coordinates of these collection places are given in the next table :

Table 7: geographical Coordinates of the places of takng of the laterites

Name of the sample	Latitude south	Longitude East
Latérite 1	18°58'51,34''	47°24'42,96''
Latérite 2	18°97'08,51''	47°42'50,47''

The following photo-satellite shows the place of collection of samples :

Source : Google earth, February 2014,

Figure 1: Localization of places of collection of laterites

We chose to study the laterite of Vontovorona in these two different zones because, according to the bibliographic survey, the laterites of these zones has contents made of different iron, therefore, we are going to determine the influence of the content made of iron of these samples during our work which finality is to determine the effect of the content made of iron on the quality of the finished product gotten by the stabilization of the laterite by micro-organisms.

IV. Presentation Of The Results

The knowledge of the geotechnical, chemical and mineralogical characteristic is indispensable for the continuation of our work. It allows:

– to determine the steps to undertake to get a product of better quality ;
– the understanding of the phenomena and reactions that occur in the biotechnical stabilization process.

4.1. Geotechnical characteristics

Table 8: The following table summarizes the geotechnical characteristics of the laterites used in this work.

Physical and mechanical feature		Latérite 1	Latérite 2
Content in natural water W (%)		13,10	5,45
Specific weight s (t/m3)		3,02	2,78
Apparent density? d (t/m3)		1,78	1,45
Pilled density	relate (has (t/m3)	1,78	1,45
	dry (s (t/m3)	1,57	1,33
Limits of Atterberg	Limit of liquidity W_l (%)	62,10	35,95
	Limit of malleability W_p (%)	40,10	24,35
	The cup flow test I_p (%)	22,00	11,60
Test of Proctor compressibility	Optimal moisture content W_{opt} (%)	26,00	20,35
	Maximal dry volume weight $\gamma_{d\ opt}$ (t/m^3)	1,62	1,75
Test of lift or Test C.B.R.	Sinking 2,5mm (%)	30,30	-
	Sinking 5mm (%)	31,00	-

According to the classification of soils in accordance with the value of their cup flow test,

– the sample named " latérite 1 " can be classified as soil having a strong malleability (15 < IP < 40). The content in optimal water is 26.00%. The indication of lift to take in account is 31.00%.
– the result shows us that this sample of soil is of a very good quality if one should use it in the construction of works or material made of earth.
– the sample named " latérite 2 " can be classified as soil having a middle malleability (5< IP <15). The content in optimal water is 20.35%.

The result of the analysis shows that the sample named " latérite 2 " is of middle quality if one should use it in the construction of the works or material in earth.

The classification following the dry density shows that our two samples have a rather mediocre appreciation.

According to the preferential zone of the Blocks of Stabilized Earth (FITZ, on 1959), our samples are classified as follows :

– laterite 1: strongly cohesive;
– laterite 2: averagely cohesive;

4.2. Particle size analysis

The result of the grading analysis by sieving of the samples of laterite taken used in this woork is summarized in the following table:

Table 9: Results of the grading analysis by sieving of the laterite 1 and 2

Module FRENCH INDUSTRIAL STANDARDS AUTHORITY	Opening of the sifter (μm)	Accrued refusal (g)	Accrued refusal (%)	Passing accumulated (%)
LATERITE 1				
37	4000	0	0	100
31	1000	10,4	5,2	94,8
28	500	50,4	25,2	74,8
25	250	62,8	31,4	68,6
22	125	90,4	45,2	54,8
20	80	108	54	46
	FLAP	200	100	0
LATERITE 2				
37	4000	0	0	100
31	1000	7,26	3,63	96,37
28	500	8,9	4,45	95,55

25	250	32,62	16,31	83,69
22	125	40,08	20,04	79,96
20	80	51,3	25,65	74,35
	FLAP	200	100	0

The grading curves by sieving of the laterites used in this work are represented by the figure below:

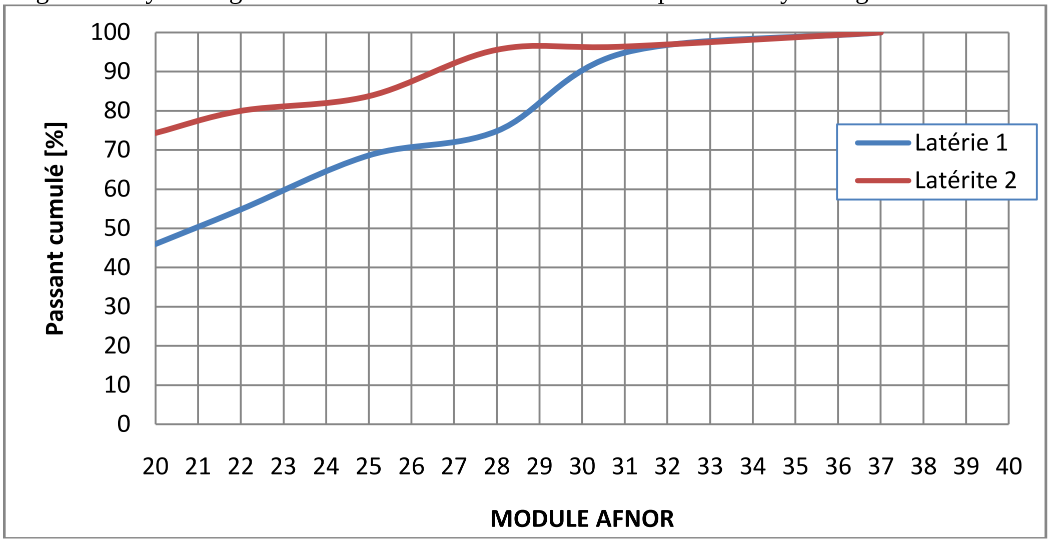


Figure 2: Curves grading by sieving of the laterite 1 and 2

The result shows that the studied samples of laterite have a fine and tight size grading. More than 46 % of elements have size lower than 80 µm and the unrefined elements are in quantity very low. Both types of laterites thus present an excess of fine particles. So, a contribution of rather unrefined sand is recommended to improve the superior hollow part.

4.3. Chemical analysis

The following table shows the content, in the shape of chemical element oxide of the two samples of laterite used in the setting of this work :

Table 10 : chemical composition of the studied laterites

Elements	**Latérite 1**	**Latérite 2**
SiO_2 (%)	31,54	13,80
Al_2O_3 (%)	25,94	45,70
CaO (%)	Trace	Trace
MgO (%)	Trace	Trace
Fe_2O_3 (%)	26,01	15,70
TiO_2 (%)	4,40	2,20
SO_3 (%)	Trace	Trace
K_2O (%)	Trace	Trace
Cr_2O_3 (%)	Trace	Trace
MnO (%)	0,21	Trace
Na_2O (%)	0,09	Trace
P_2O_5 (%)	0,51	Trace
Ignition loss (%)	11,29	19,00

The table shows that our laterites is very rich in oxide of III iron (Fe_2O_3), we also note the difference between the content made of iron of the two shamples : the laterite 1 has a content made of very elevated iron, of the order of 26,01%, while the laterite 2 is constituted of 15,70% of iron oxide, only.

Furthermore, we notice the important quantity of the other elements as the aluminum oxide and the oxide of silicon. And according to Martin's classification and Dean, who bases himself on the following formula:

$$K'_i = \frac{\frac{SiO_2}{60}}{\frac{Al_2O_3}{102} + \frac{Fe_2O_3}{160}}$$

Ki ' (laterite 1) = 1,29

Ki ' (laterite 2) = 0,42

Our laterites can be classified as true laterites that is to say Ki ' < 1,33

4.4. Study of the stabilization of the laterite by microorganisms

The process of stabilization can be schematized as follows :

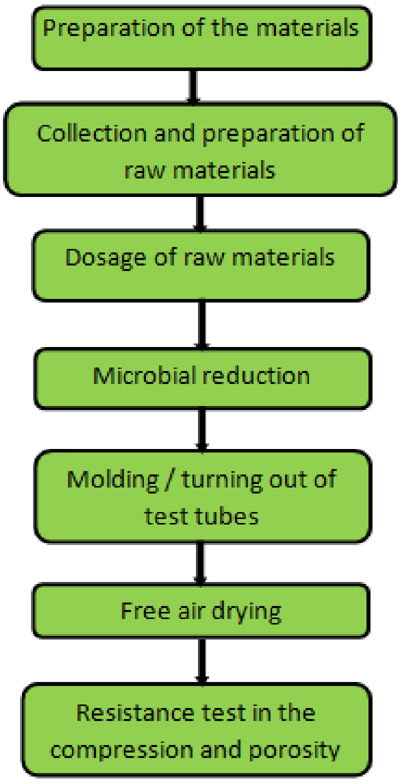


Figure 3: The process of stabilization

4.5.1. Principle of the stabilization

Microorganisms can use the ferric iron as acceptor of electrons. Its reduction establishes an important form of anaerobic breathing that is in absence of oxygen of the air. The ferric iron can form complexes with numerous organic compounds, which makes afterward soluble and again available as acceptor of electron for the reducing bacteria. The ferric hydroxide recently formed can interact it with other non-biological substances, as humic substances to reduce the ferrous iron into ferric iron.

The reaction corresponding to this reduction of the ferrous iron into ferric iron can presented as follows:

$$Fe^{3+} \xrightarrow[\text{en milieu anaérobie}]{\text{réduction microbienne}} Fe^{2+}$$

In presence of the air oxygen (during the drying) the ferrous iron (that is very unsteady) oxidizes in ferric iron.

4.5.2. Methodological approach

Twelve (12) samples have been prepared which composition is given in the following table :

Table11 : Composition of every sample

N°	Latérite 1 (%)	Latérite 2 (%)	Sand (%)	Oxide of iron (%)	Sugar (%)	Urea (%)	Manure of ox
1	100	-	-	-	-	-	-
2	100	-	-	-	-	-	saturation
3	95	-	5 (0,08 - 2,5mm)	-	-	-	saturation
4	95	-	5 (0,08 - 1 mm)				saturation
5	-	95	5 (0,08 - 1 mm)	-	-	-	saturation
6	-	90	5 (0,08 - 1 mm)	5	-	-	saturation
7	-	85	5 (0,08 - 1 mm)	10	-	-	saturation
8	90		5 (0,08 - 1 mm)	5	-	-	saturation
9	90	-	5 (0,08 - 1 mm)	-	5	-	saturation
10	85	-	5 (0,08 - 1 mm)	-	10	-	saturation
11	85	-	5 (0,08 - 1 mm)	-	5	5	saturation
12	80	-	5 (0,08 - 1 mm)	-	5	10	saturation

The goal of these different tests of experimentations is to determine the optimal parameters of the stabilization of the laterite by micro-organisms.

The test consists in determining the evolution of the Fe^{2+}/Fe^{3+} relation, the resistance to the compression to the dry state and to the humid state as well as the porosity of the test-tubes.

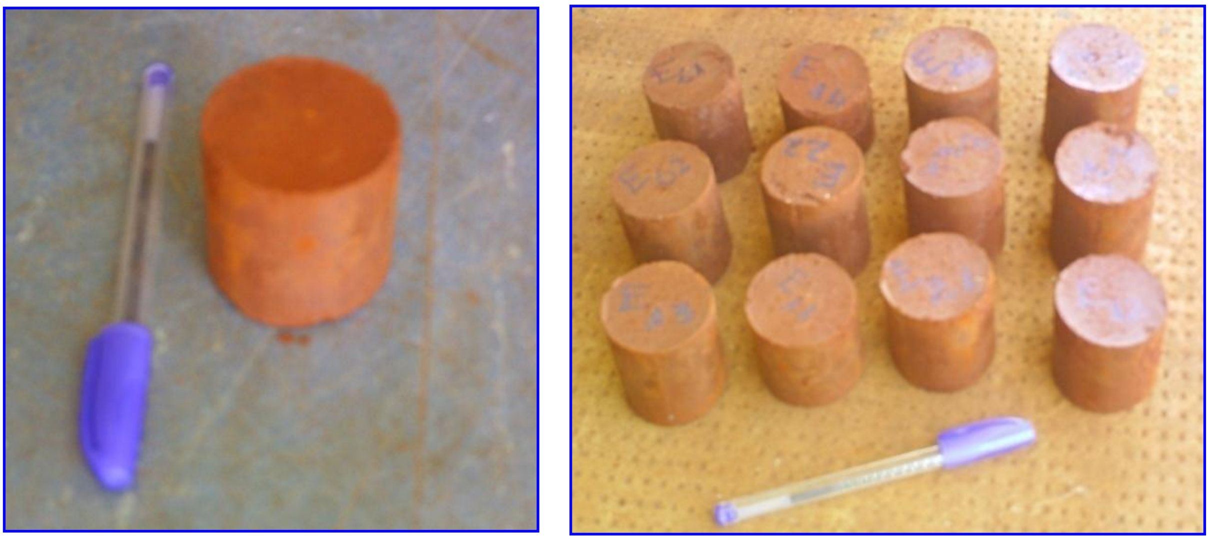


Figure 4: Some samples of test-tubes gotten

4.5.3. Results and discussions

4.5.3.1. Evolution of the Fe^{2+}/Fe^{3+} proportion/ration in relation to the processing time

a) Effects of the activation of the reduction of the Fe^{3+} in Fe^{2+} by the addition of manure, sugar and urea

The tests N ° 1, 2, 9 - 12 were realized to verify the reaction of microbial reduction of laterite by activating the reaction by manure, sugar and urea which are sources of microorganisms and nutriment.
The results of the essays are given by the following figure :

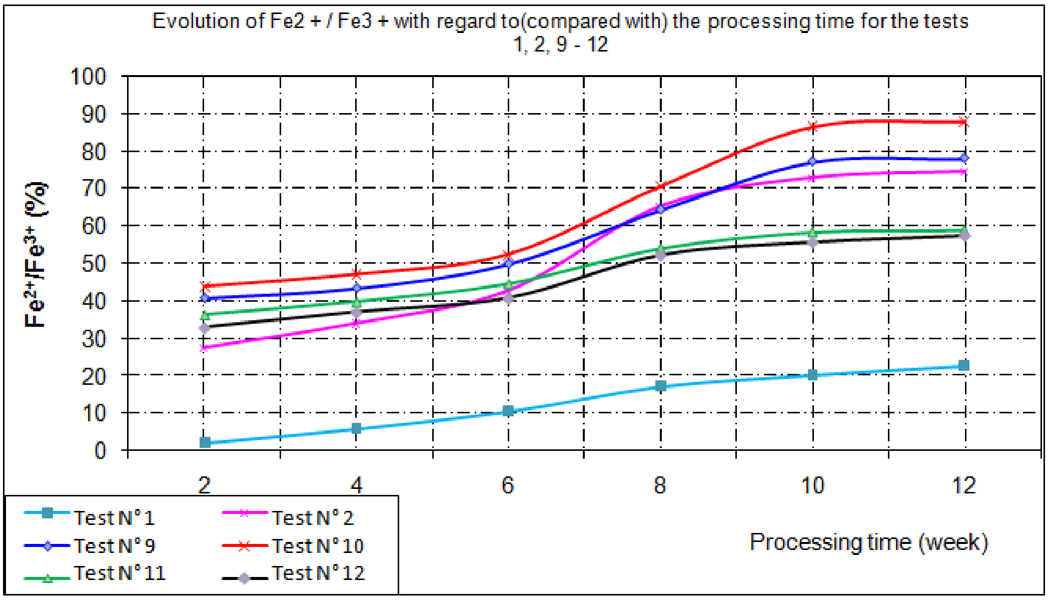


Figure 5 : Evolution of Fe^{2+}/Fe^{3+} with regard to the processing time for the tests 1, 2, 9-12

The diagram above shows that :

- manure brings the elements necessary to the growth and to the high-speed multiplication of the micro-organisms. It assures the densification of the reducing micro-organisms of the ferric iron. Indeed, without manure, 23% of ferric iron has only been reduced in II iron after 12 weeks of treatment. Whereas the contribution of manure increases the speed of reduction extensively. The speed of the microbial growth is so important between the 6th and the 8th week, the rate of ferric iron reduced passes from 43 to 65%. However, it decreases little by little from the 8th week, because the ferric oxide contained of the sample begins to exhaust itself, then it stabilizes from the 10th week. After 12 weeks of treatment, 75% of ferric iron has been reduced into ferrous iron. Therefore, from the 10th week, the activities of the micro-organisms are weak.

- the contribution of sugar improves the reduction of the ferric iron made of ferrous iron appreciably. The speed of formation of $Fe2+$ is so important between the 6th and the 10th week. When one increases the quantity of sugar in mixture, the speed of reduction of the ferric iron made of ferrous iron improves appreciably.
- the addition of urea with sugar improves the speed of formation of II iron slightly until the 6^{th} week of treatment. However, this contribution inhibits the bacterial activity from the 6^{th} week, the more the added quantity is raised, the more the inhibition is important.

  Then, we can say that the reducing microorganisms of the ferric iron into ferrous iron need only hydrocarbon materials to develop, they do not need nitrogenous materials.

b) Effects of the content made of iron of the laterite on the bacterial activities

The tests N° 2 and 5 to 8 have been achieved to study the reaction of the micro-organisms in relation to the content in oxide of iron of the laterite as well as the external contribution of iron oxide to correct the weak content.

The following diagram shows the result of the tests N° 2, 5 to 8 :

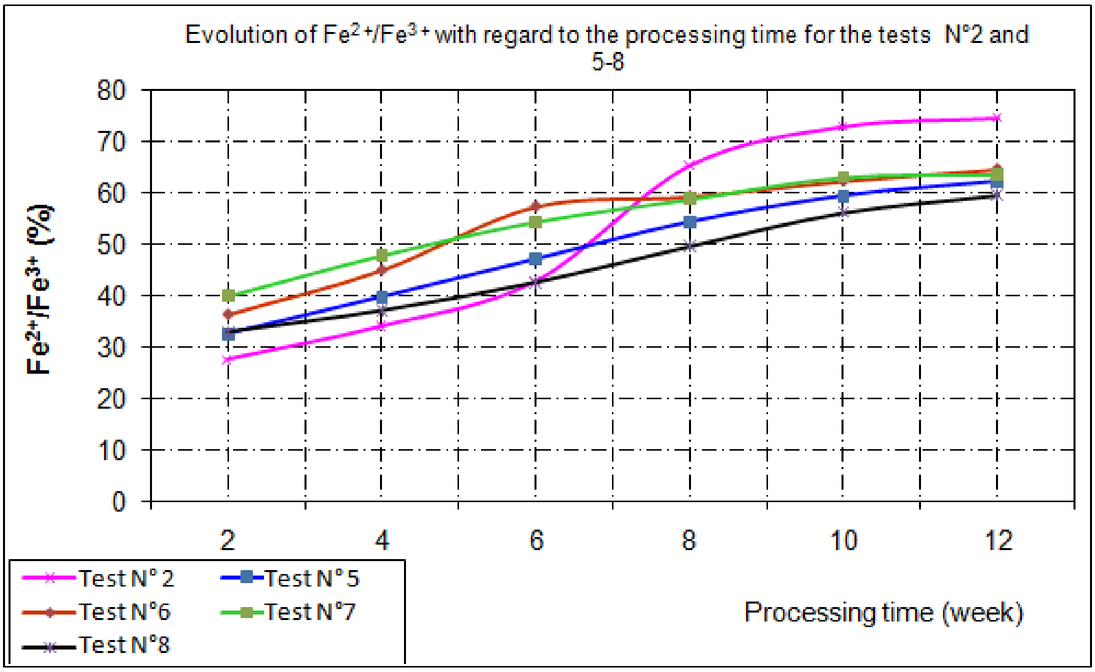


Figure 6 : Evolution of Fe^{2+}/Fe^{3+} with regard to the processing time for the tests 2 and 5-8

The diagram above shows that :

- the content in initial oxide of iron of the laterite influences a lot on the activities of the micro-organisms for the reduction of the ferric iron into ferrous iron. Indeed, when the content in oxide of iron is weak, the speed of formation of the ferrous iron increases slowly according to the time (laterite 2 + manure). However, when the content in oxide of iron is raised, the speed of formation of the ferrous iron increases slowly until the 6th week, then it increases quickly until the 8th week, then it stabilizes slightly until the 12th week (test N° 2 : laterite 1 + manure). On the other hand the reduction of the Fe^{3+} into Fe^{2+} evolves slowly from 2 until the 12^{th} week of treatment for the laterite 2 (test N° 5) ;
- the contribution of 5% of iron oxide to the latérite 2 (content in oxide of iron 15.70%) improves the speed of formation of the ferrous iron slightly. However, the increase of the contribution by 10% of iron oxide doesn't nearly have an impact on the speed of the reduction of the ferric iron into ferrous iron (test N° 6 and 7) ;
- the addition of 5% of iron oxide to the laterite 1 (content in oxide of iron 26.01%), to strong content in oxide of iron inhibits the bacterial activity of the reduction of the ferric iron into ferrous iron (test N° 8).

4.5.3.2. Compression resistance

a) Effects of the activation of the bacterial activities by manure, sugar and urea

a.1) Compression resistance in the dry state

The following figure shows the evolution of the compression resistance in the dry state of the test-tubes of the tests N° 1, 4, 9 to 12 :

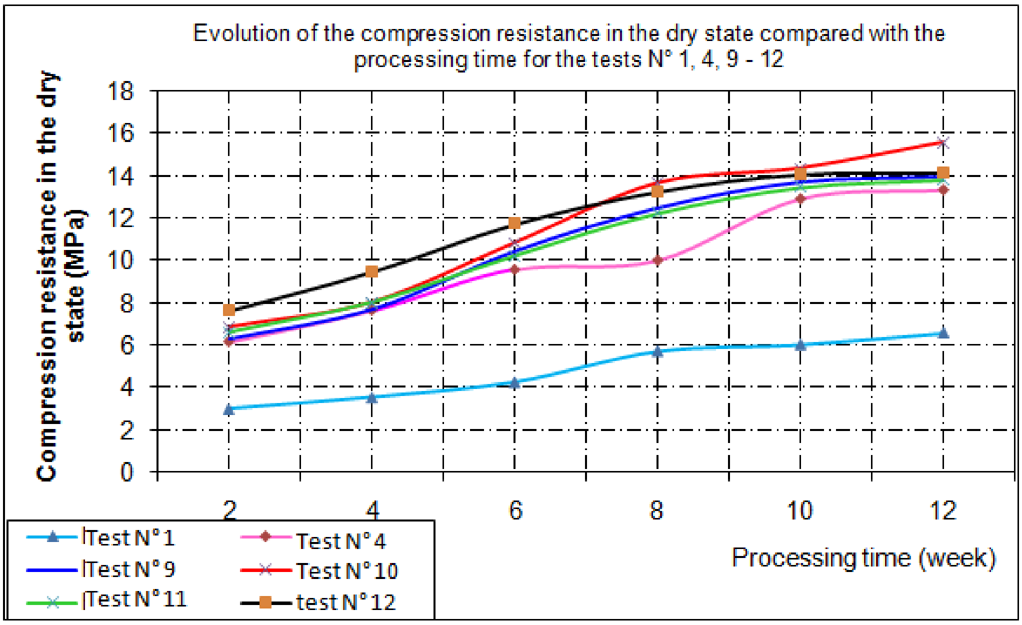


Figure 7 : Evolution of the compression resistance in the dry state compared with the processing time for the tests 1, 4, 9 - 12

The diagram above shows that the resistance to the compression to the dry state of the test-tubes gotten during the tests N° 1 and 4, increases progressively according to the time. This increase is a lot more important between the 6th and the 8th week, and then it decreases little by little to stabilize from the 10th week.

The gotten results show well that the mechanism of hold of the test-tubes is assured by the reduction of the Fe^{3+} into Fe^{2+} by micro-organisms in anaerobic environment, followed its oxidization by the oxygen of air during the drying.

The contribution of micro-organism and nutriments through the intermediary of manure accelerates considerably the hold. The resistance to the compression in the dry state nearly doubled after 12 weeks of treatment, by the addition of combined manure to the adequate granulometric correction (test N° 4). The resistance to the compression of 6.57 MPa for the test N° 1 passed to 13.57 MPa for the test N° 4.

The contribution of sugar improved the resistance to the compression in the dry state of the test-tubes. Indeed the contribution of 5% of sugar to improved of 0.65 MPa the resistance to the compression to the dry state of the test-tubes, while the addition of 10% of sugar gave an improvement of the resistance to the compression in the dry state of 2.27 MPa, after 12 weeks of treatment (tests N° 9 and 10).

The contribution of mixture of sugar and urea improved the resistance to the compression in the dry state of the test-tubes. This improvement is very important until the 7th week of treatment for the addition of 5% of sugar and 10% of urea (tests N° 11 and 12). However, this increase of the resistance to the compression in the dry state is less important in relation to the addition of 10% of sugar, of the 8th until the 12th week of treatment.

The resistance to the compression in the dry state of 13.32 MPa, gotten with the N°4 test after 12 weeks of treatment, is only reached after only 7 weeks by the addition of 10% of sugar or 5% of sugar in addition 10% of urea to the latérite 1.

a.2) Compression resistance in the wet state

The evolution of the resistance to the compression in the wet state of the test-tubes of the essays N°1 2 and of 9 to 12 is summarized by the following figure :

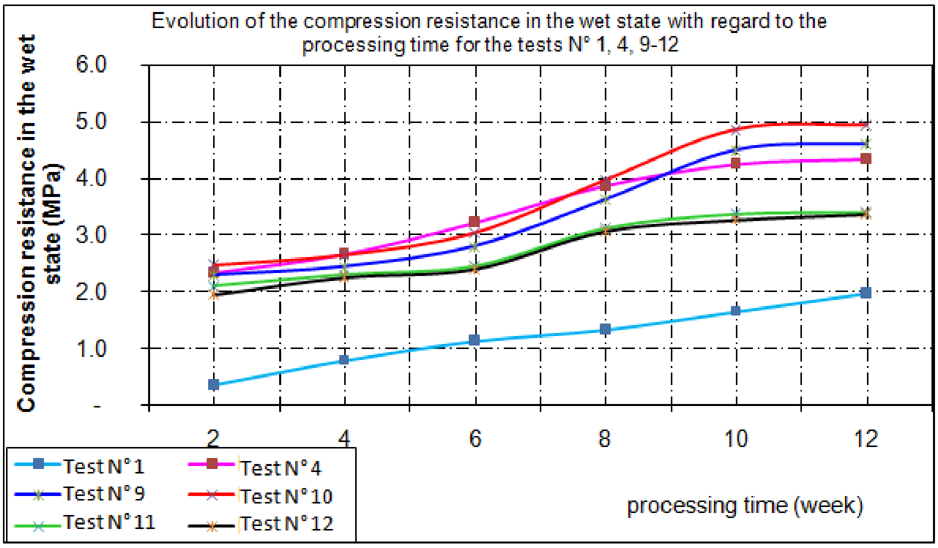


Figure 8 : Evolution of the compression resistance in the wet state with regard to the processing time for the tests N° 1, 4, 9-12

The figure above shows well that the test-tubes gotten by this process resist water. The addition of manure improved the mechanical strength considerably in the humid state of the test-tubes. The value of the mechanical strength gotten doubled. It passed from 1.96 to 4.34 MPa.

The granulometric correction doesn't bring much to the mechanical strength, in the humid state. It passed from 4.24 to 4.34 MPa, that is an increase of 0.10 MPa only.

The contribution of 5% of sugar didn't improve the resistance to the water of the test-tubes except from the 9th week of treatment. We noted an increase of the resistance to the compression in the humid state by 0.26 MPa after 12 weeks of treatment. However, the addition of 10% of sugar improved the resistance to the compression in the humid state of the test-tubes that from the 8^{th} week of treatment. One noted an increase by 0.60 MPa, after 12 weeks of treatment by micro-organisms.

However, the contribution of the urea in addition to sugar affected the resistance to the water of the test-tubes. One can explain this reduction of the resistance to the compression in the humid state of the test-tubes by the retention of water of the urea that affects the link of the aggregations that composes the material.

b) Effects of the content made of iron of the laterite on the bacterial activities

b.1) Compression resistance in the dry state

The evolution of the compression resistance in the dry state of the test-tubes according to the time, of the tests N° 4 to 8 is given by following figure :

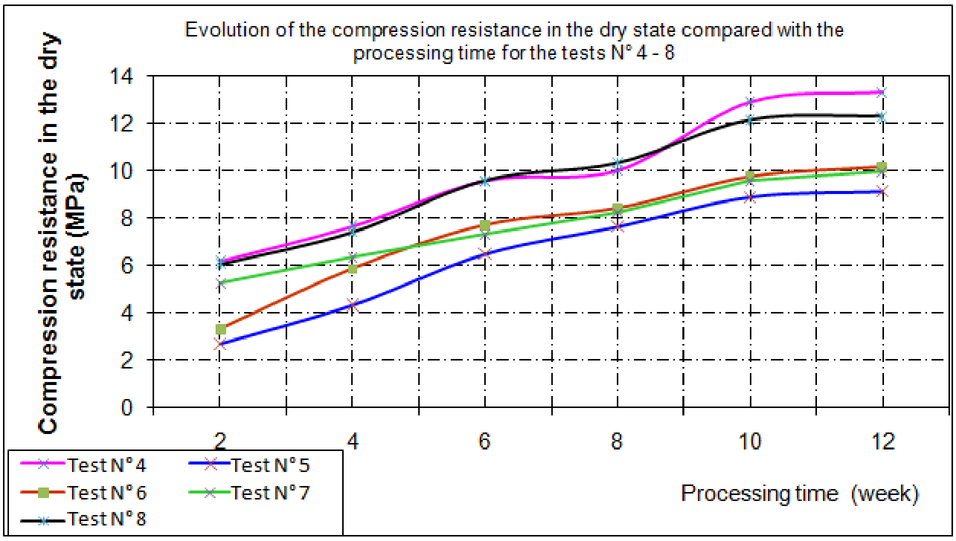


Figure 9: Evolution of the compression resistance in the dry state compared with the processing time for the tests N° 4 - 8

The figure shows the results of the stabilization of the laterite 1 and 2 as well as the addition of iron oxide in these samples of laterites by micro-organisms. We note that the natural content made of oxide iron of the laterite plays a very important role in the process of stabilization, especially on the resistance to the compression in the dry state of the test-tubes.

The more the content in oxide of iron is raised the more the resistance to the compression in the dry state is raised. Indeed, for the laterite 1 which content in oxide of iron is 26.01%, the resistance to the compression in the dry state is 13.32 MPa while for the latérite 2, 15.70% of iron oxide, equals in 9.10 MPa, after 12 weeks of treatment, therefore a gap of 4.2 MPa has been noted.

It is for this reason that we added the oxide of iron to the laterite 2 to correct its content in oxide of iron.

So the contribution of 5% of iron oxide entailed a light increase of the resistance to the compression in the dry state. We noted a light improvement of 1.05 MPa. However, the increase of the contribution of iron oxide or 10% entailed a light reduction of the resistance to the compression in the dry state. It can be due to the presence of the iron oxide in too elevated quantity in the laterite that affected the cohesion of the aggregats of the test-tubes.

In the same way, the addition of 5% of iron oxide to the laterite 1 has caused a light reduction of the resistance to the compression in the dry state of the test-tubes, that is a gap of 0.65 after 12 weeks of treatment by micro-organisms.

b.2) Compression resistance in the wet state

The evolution of the resistance to the compression in the humid state of the test-tubes according to the time, of the tests n° 4 to 8 is given by the following figure :

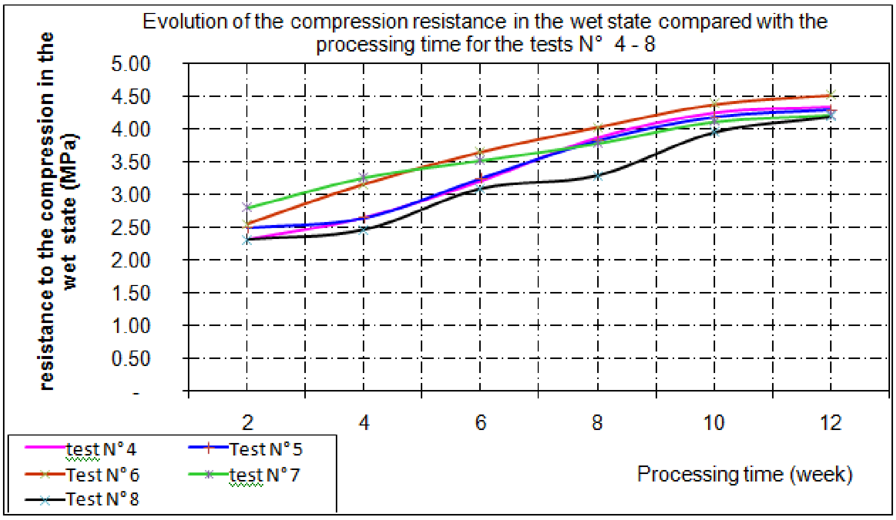


Figure 10: Evolution of the compression resistance in the wet state compared with the processing time for the tests N° 4 – 8

The figure above shows that the resistance to the compression in the humid state of the test-tubes gotten by the stabilization of the laterite 1 (content in oxide of iron 26.01%) and the one of the laterite 2 (content in oxide of iron 15.70%) is nearly the same during the treatment. One noted a small gap of 0.05 MPa, after 12 weeks of stabilization by micro-organisms. Then, we can say that the content in oxide of iron of the laterite doesn't have an impact on the resistance to the compression in the dry state of the test-tubes.

The external contribution of 5% of iron oxide to the laterite 2, improves the resistance to the water of the material. We noted a gap of 0.23 MPa, after 12 weeks of treatment. While the addition of 10% of iron oxide to the laterite 2, improves the resistance slightly to the compression until the 8th week. Then it remains lower to the resistance to the compression in the humid state of the test-tubes of the laterite 2 until the 12th week. One noted a small gap of 0.08 MPa, after 12 weeks of stabilization by micro-organisms.

The resistance to the compression in the humid state of the laterite 2 (4.29 MPa), after 12 weeks of treatment is reached after 9 weeks of treatment, only, by the addition of 5% of iron oxide.

The contribution of 5% of iron oxide to the laterite 1 affects the resistance to the water of the test-tubes.

For the tests N°7 and 8, the reduction of the resistance to the compression to the humid state is can be due to the modification of the granulometry of the laterite by the presence of fine particle excess in the finished product.

4.5.3.3. Porosity

a) Effects of the activation of the bacterial activities by manure, sugar and urea

The following figure shows the evolution of the porosity of the test-tubes according to the processing time of the tests N° 1, 4 and of 9 to 12 :

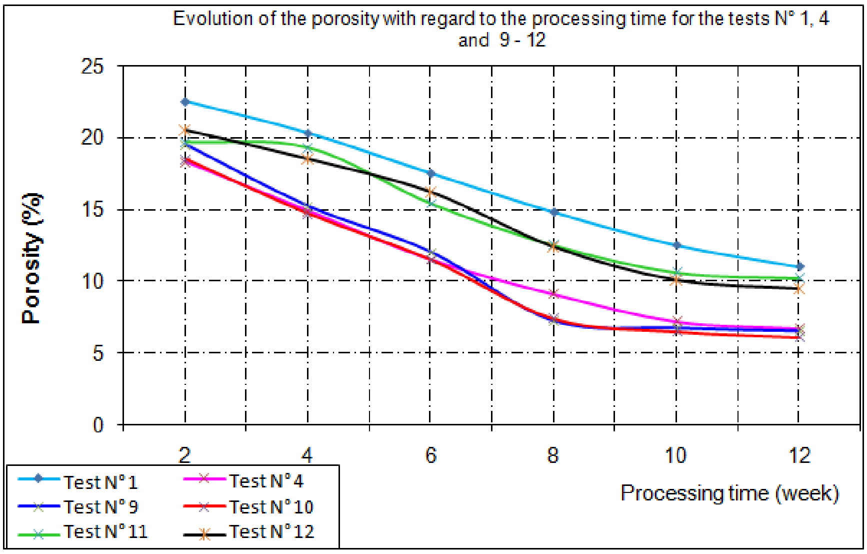


Figure 11 : Evolution of the porosity with regard to the processing time for the tests N° 1, 4 and 9 - 12

The figure above shows that, the porosity of the test-tubes decreases according to the processing time. This evolution is very remarkable in the case of the fourth test with which we added manure combined to an adequate granulometric correction. Thus, the final porosity, after 12 weeks of 11% for the test N° 1 (laterite + water) passed to 6.9% in the case of the test N° 4 [laterite + sand (0.08 to 1mm) + manure].

Therefore, the activation of bacterial activities by manure decreases the porosity of the material considerably because the created emptiness remained weak. This phenomenon has an important impact on the quality of the material because the possibility of penetration of the water (which alters the connection of aggregates) inside the material is tiny.

The contribution of sugar (tests N° 9 and 10) improves the porosity of the test-tubes considerably. We still noted an improvement of the porosity of 0.6% in relation to the test N° 4 for the addition of 5% and 1% for the contribution of 10% of sugar, after 12 weeks of treatment.

However, the addition of the urea to the mixture (tests N° 11 and 12) affects the porosity of the test-tubes. One noted a maximal gap of 4.1%, which confirms the reduction of the resistance to the water of these test-tubes containing urea, above stated.

b) Effects of the iron content of the laterite on the bacterial activities

The following face shows the evolution of the porosity of the test-tubes according to the time, of the tests N° 4 to 8 :

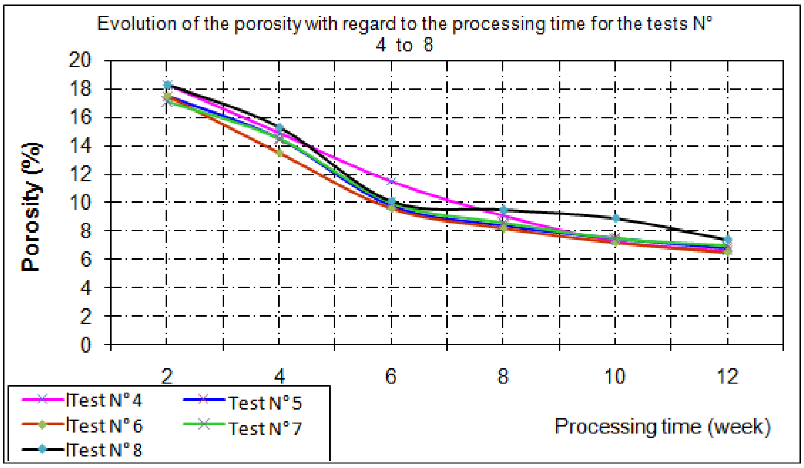


Figure 12: Evolution of the porosity with regard to the processing time for the tests N° 4 to 8

The diagram above shows that the content in oxide of iron of the laterite does not have any influence on the final porosity of the test-tubes gotten by the stabilization of the laterite by micro-organisms after 12 weeks of treatment. We noted a small gap of 0.2%, between the two studied laterite samples after 12 weeks of stabilization by micro-organisms.

The external contribution of 5% of iron oxide improved the porosity of the laterite 2. One noted a small increase of 0.3%, after 12 weeks of treatment. However, the addition of 10% of iron oxide increases the porosity of the test-tubes by 0.2%.

The contribution of 5% of iron oxide to the laterite 1 affected the porosity of the test-tubes gotten from this laterite. One noted an increase of 0.8% after 12 weeks of treatment by micro-organisms.

4.5.4 Comparison of the result gotten with the other methods of stabilization

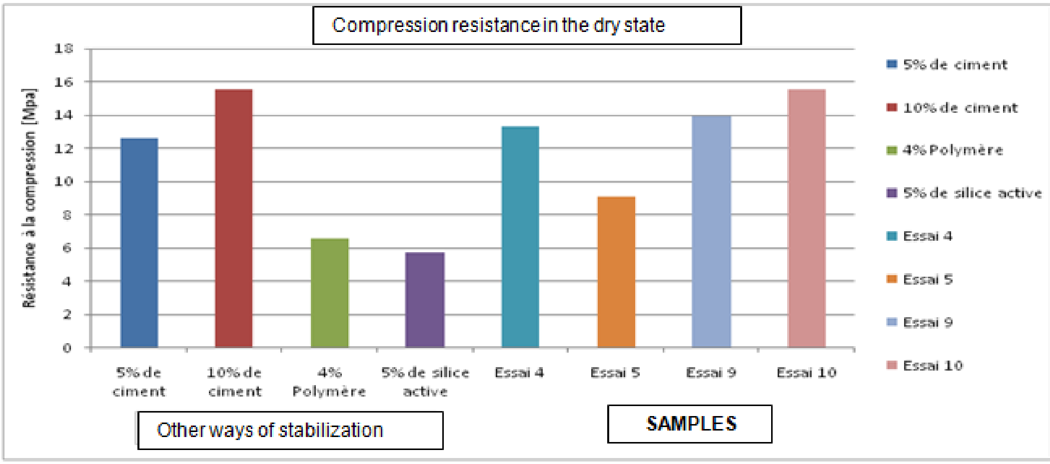
In order to situate the quality of the material gotten by stabilization of the laterite by micro-organisms, we did some comparisons with the classic ways of stabilization as the use of cement, polymers or active silica, coupled to the urea.

So, we compared our results to those obtained by other researchers. The following table summarizes the results of this comparison :

Test	Compression resistance in the dry state (MPa)	Compression resistance in the humid state (MPa)	Middle porosity (%)
5% of cement	12.59	3.91	18.3
10% of cement	15.55	6.12	16.9
4% of polymer reverseal 16	6.60	2.97	12.56
5% of active silica	5.75	2.00	7.0
Test N° 4	**13.32**	**4.34**	**6.6**
Test N° 5	**9.10**	**4.29**	**6.8**
Test N° 9	**13.97**	**4.69**	**6.5**
Test N° 10	**15.59**	**4.94**	**6.1**

Source : Rabotovao O.M., ESPA 2007, Rakotonirina J.A., ESPA 2010, Author

The following figures summarize the result of this comparison :



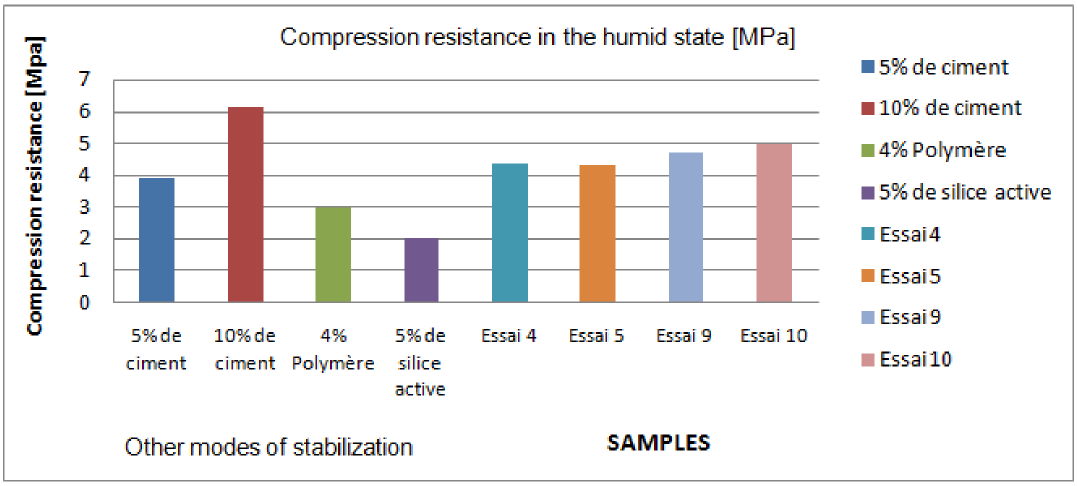
According to this diagram, the compression resistance in the dry state of the tests-tubes gotten from the stabilization by the microorganisms of the tests N ° 4, 9 and 10 are better in relation to the stabilization with :

– 5% of cement ;
– 5% of active silica coupled with urea ;
– 4% of polymer Reverseal 16.

However, it is less good in relation to the stabilization with 10% of cement. The test-tubes gotten by the addition of 10% of sugar nearly have the same resistance to the compression in the dry state as the one gotten by the stabilization to 10% of cement.

By extrapolation, the resistance to the compression in the dry state of the product gotten with the test :

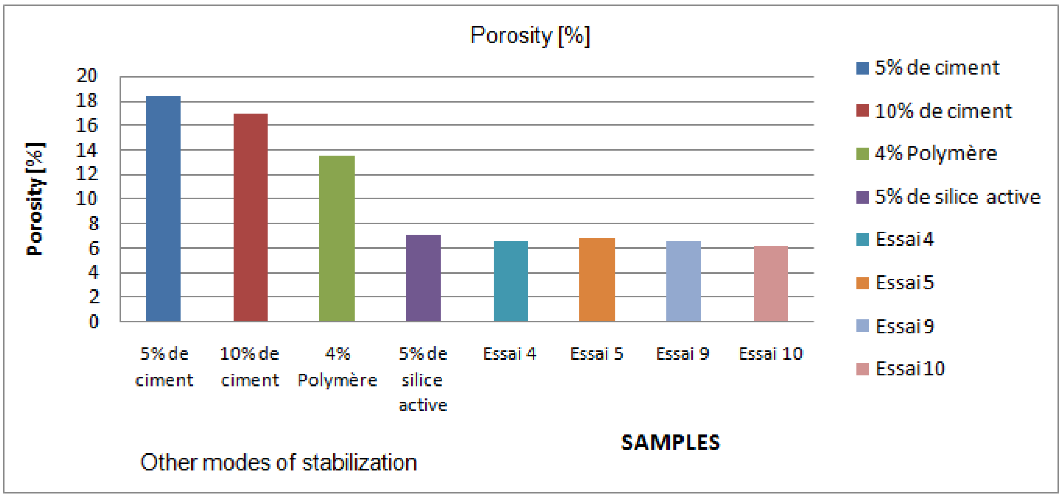
– N° 4 is equivalent to a material consolidated by the cement to 6.72%,
– N° 9 is equivalent to a material consolidated to 6.82% of cement ;
– N° 10 is equivalent to a material consolidated to 7.79% of cement.



According to this diagram, the resistance to the compression in the humid state of the test-tubes gotten from the stabilization by microorganisms of the tests N° 4, 5, 9 and 10 is better in relation to the stabilization with :

- 5% of cement ;
- 5% of active silica coupled to the urea ;
- 4% of polymer Reverseal 16.

However, it is less good in relation to the stabilization to 10% of cement.



Concerning the porosity, the stabilization by microorganisms is the best. Even though the stabilization with 10% of cement gave the best result on the resistance to the compression (in the dry or humid state), the product gotten nearly presents 3 times of pores in relation to the one gotten by biologic process.

V. Conclusion

The studies achieved in the setting of this work allowed us to demonstrate that it is possible to do the stabilization of the laterite by microorganisms for the building material manufacture. Indeed, after a bibliographic survey on the laterite, the stabilization technique, the geotechnical characterization, the mineralogical, physic and-chemical of the main raw material, we did tests of stabilization of the laterite by microorganisms. The tests allowed us to determine the best conditions of material obtaining based on laterite consolidated by microorganisms. Worth knowing :

- the activation of the microbial reduction by the manure of oxen,
- the granulometric correction of the laterite by sand of a granulometry between 0.08 to 1 mm, class 0/1,
- the optimal microbial reduction time of the iron oxide is 10 weeks, to the ambient temperature,
- the addition of sugar can improve the resistance to the compression while the contribution of the urea affects the resistance to the water of the material.

The tests gave satisfactory results regarding compression resistance in the dry state, compression resistance in the humid state and to the level of the porosity.

The activation of the reaction by the manure of oxen followed by an adequate grading correction gave the following results :

- a resistance to the compression in the dry state of 13.32 MPa s;
- a resistance to the compression in the humid state of 4.34 MPa s;
- a porosity of 6.6%.

The addition of 10% of sugar in the mixture improved this result, worth knowing ,:

- a resistance to the compression in the dry state of 15.59 MPa s;
- a resistance to the compression in the humid state of 4.94 MPa s;
- a porosity of 6.1%.

Compared to the results gotten by other researchers on the stabilization of the laterite by cement, of the lime, the active silica coupled to the urea as well as by polymeric Reverseal 16, the material consolidated by microorganisms is better compared with the stabilization to 5% of cement, or 5% of lime + 5% of cement or active silica + urea in 5% or the Reverseal 16 to 4% considering resistance to the compression (in the dry state or in the humid state) and to the level of the porosity.
Thus, this method is a lot more profitable on the technical, economic and financial plan. It also procures the best result regarding the protection of the environment.

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