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Thermo-Mechanical Properties Study of Stabilized Soil Bricks to Sugar Cane Molasses and Cassava Starch Binders

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Abstract

The current study deals Swith thermo-mechanical properties of stabilized soil small bricks with the help of organic binders of sugar cane molasses and cassava starch. Different formulations of soil concrete have been suggested after the geotechnical characterization of samples of soil was taken. From these, it arises that the studied soil is the most plastically clay (of type A_3) according to GTR classification. Samples made of small bricks and measured out at 4%, 6% and 8% of binders (molasses, starch or molasses + starch) have been warmed up to different temperatures (100˚C, 150˚C, 200˚C and 250˚C) for the rising of the thermic behavior under different conditions and submitted to crushing testings for the estimation of characteristic resistances to the compression. According to the mechanical behavior, we note an improvement of resistances for small bricks measured 4%, 6% and 8%, of molasses respectively of 32.44%, 32.06% and 23.43% against the value of reference for small bricks without molasses. In the same way, the binder (molasses + starch) also reveals an improvement of resistance to the compression of 13.27%, 26.17% and 26.17%. On the contrary, the stabilization with the starch binder did not bring a significative improvement. According to the thermic influence, the heating at 100˚C of stabilized small bricks at 4%, 6% and 8% of molasses, reveals a significative improvement of resistances. Moreover, the stabilization with the starch reveals on the contrary a good behavior for heatings at 150˚C and 250˚C. In short, for the binder (molasses + starch), it is the heating at 200˚C that shows some improvements of remarkable resistances. Different analyses of realized statistics also show the effectivity of obtained results. For all realized formulations, the measuring out at 6% of binders (molasses, or molasses + starch) seems as optimal in front of the best thermo-mechanical revealed properties.

Keywords

Clay, Molasses, Cassava Starch, Heating, Compressed Soil Brick, Mechanical Resistance

1. Introduction

The earth warming has become nowadays evidence by climate changings which are observed. For that, climate patterns announce that the temperature of our planet will increase from 1.4˚C to 5.8˚C from now to 2100 according to research works that have already been conducted. So, those projections rest on a large fan-shaped of hypopheses about principle factors that are at the origin of greenhouse gas emissions, and among them, anthropic activities [1]. It is for this reason that it is essential to control recurrent changing by adapting measures as it is the case of materials in the field of residence buildings. Thus, this really passes by the development of new ecological materials in order to answer to the needs of building and of adaptability for the sake of moving, from bio-resources towards bio-lodgings. For that, the material "soil" is on a good place. The usage of this material at weak environmental impact, is one of the solutions which presents many advantages in ecological level, economic, and social as well [2] [3]. This, constitutes not only a strong encouragement to the innovation of those construction materials, but also, a way to integrate into the context of sustainable development.

Hence, the development of the construction with the material soil is therefore a real alternative in order to reduce greenhouse gas in the sector of residence building, contrary to concrete material for example.

Though easily available, the soil has been used following different technics, according to regions and depending on its characteristics. Since ancient days, clayey materials constitute complex natural mixtures in which the granulometry and physic-chemical properties are very changeable [4] [5]. Nowadays, about 1500 billions of bricks are produced every year. This implies more than 4000 millions of tons of treated clay extraction for more than 1,000,000 ovens to grand scale. For the drying of bricks, choice criteria of users are less linked to the global chemical composition of clayey materials [6].

Nevertheless, this clayey material has a weak point; it is its big sensibility in humidity and in water, from which the necessity to maintain it in good state [7]. Now, in order to remedy it, it is necessary to stabilize it. Therefore, the traditional technology of construction with soil has undergone considerable developments that improve the durability and the thermo-mechanical behavior of blocks of soil as well in the construction industry.

Here, different methods and practices comprise the built soil, stabilized soil bricks (BTC), bricks of raw soil, cooked soil, which are obtained thanks to different methods of making.

In our case, the use of stabilizing products like sugar cane molasses or the starch, considered as organic binders, has shown the interest. Therefore, works by [8] and [9] have shown that most of industrial applications and scientific works in the frame of the stabilization of raw soil bricks have resorted for many, to cement in which the borrowing carbonate is higher. So, it is today essential to go in for bio-resources as binder to reduce sufficiently greenhouse gas effect and promote the sustainable development.

In another hand, studies carried out by Tamba and al (2015), Malanda and al (2019), Ngouallat and al (2020), Malanda, and al (2022), Ngouallat and al, 2014 and P'KLA (2002), have allowed to evidence the contribution of the molasses in the value of small soil bricks proceeding to the improvement of mechanical properties like the characteristic resistance to the compression according to molasses dosages [10]-[15]. In the same way, Marcedo De Souza and al (2021), Ngouama (2008), in their works on the optimization of stabilized raw soil bricks with the help of cassava flour gel, have also shown a considerable improvement of mechanic resistances [16] [17]. But, many problems occur again about the thermo-mechanical behavior of this small bricks [10] [11] [17] [18] [19] and [20].

So, the aim of this study is to evaluate the thermo-mechanical behavior under different temperatures, of stabilized small bricks with the help of the molasses or the starch, or with the mixture molasses + starch according to different dosages of those binders. This study proposes therefore a good compromise between mechanic and thermic performances of those materials (samples obtained after the formulation of this concrete soil).

2. Material and Methods

2.1. Material

2.1.1. The Sugar Cane Molasses

The sugar cane molasses is a by-product (residue) from the sugar cane. Very viscous, it is obtained in the process of manufacture and of sugar refining. For this study, the used molasses comes from sugar bowl company "Saris Congo" located in the city of N'Kayi; a South region of the Republic of Congo, of which the Latitude: -4˚10'58.22" and the longitude: 13˚17'11", from geographical coordonates. In general, the chemical composition of the molasses as an indication is shown in **Table 1**.

2.1.2. The Cassava Starch (Tuber)

The cassava starch includes from 14% to 24% of amylose, the similar value to those from tuber starches (19% - 23%), but inferior to those of cereal starches (26% - 28%) and of vegetables (33% à 35%). For our study, the starch has been obtained from the production of cassava in the locality of Madingou (**Figure 1**), [18].

Table 1. Chemical composition sugar cane molasses [21].

Components	Quantity
Drying materials (MS) (%)	73
Mineral Materials (%MS)	14
Total Nitrogen Materials (%MS)	6
Total sugar (%MS)	64
Calcium (g/KgMS)	7.4
Phosphor (g/KgMS)	0.7
Potassium (g/KgMS)	40

N.B.: % MS means % of dry material, that is other contents are given in % of the dry material. For example, for 73 g of the dry material, we will have a content in total sugars equals to 64% of the MS, or 46.72 g. In total: mineral materials, nitrogen materials, total sugars = 10.22 g + 4.38 g + 46.72 g = 61.32 g < 73 g [10].

Figure 1. Sample of cassava starch.

2.2. Methods

2.2.1. Geotechnical Tests

The realized tests in the frame of geotechnical characterization of the used soils are: The granulometric analysis by sieving and filtering, the granulometric analysis by sedimentometry, the limits of Atterberg, the proctor normal test, the compactage test, the resistance to the compression (**Figures 2-5**). The used clayey soils in the frame of this study have been taken in the locality of Madingou (department of Bouenza). These geographical coordinates are the following: Latitude: -4˚9'12S Longitude: 13˚33'0E. Samples have been done around 50 cm deep compared with the natural terrain (TN). The curvature coefficients and of the uniformity have been determined by the following formula:

$$C_U = \frac{D_{90}}{D_{60} \times D_{10}}$$

$$C_c = \frac{D_{60}}{D_{10}}$$

2.2.2. Method of Soil Bricks Making

Small bricks have been made with a manual compactness, a mold of dimensions 16 × 4 × 4 cm^3, used for the making of small bricks following percentages in binder varying from 4%, 6% and 8% for the molasses or the cassava starch, and the mixture molasses plus starch (**Figure 5**).

Figure 2. Memmertaven study (001/GM (P) and mass of Sieve 150.

Figure 3. Equipments for Attererg limits and balance of precision of type Brand KERN 400-47.

Figure 4. Universal Press for measure of the mechanic resistance Mécaniques type IGN.

Figure 5. Sample of stabilized clay small bricks to molasses and starch binders.

In the frame of this study, the dosage in binder has been power weight. Nevertheless, for the dosage of the molasses, the quantity of water is added to the material soil according to those obtained during the Proctor Test.

The homogeneity of the mixture is determinant for the quality of small bricks. Also, have we proceeded to a hand mixture during 5 to 10 minutes [10]?

2.2.3. The Drying of Braised Soil Bricks

The drying has been done braised at different temperatures (100˚C), liquid water is transformed into vapor thanks to the contribution of the heat and the vapor of formed water is evacuated.

2.2.4. Mechanic Resistance to the Compression

The tests of compression are realized on the small bricks after drying for samples having the age from 7 to 28 days, and taken at different contents of molasses and of starch or of molasses plus starch at 0%, 4%, 6% and 8%. These small bricks have been warmed at varying temperatures of 100˚C, 150˚C, 200˚C and 250˚C. For that, three samples of the same content in stabilizing have been braised warmed. And, for each of these reserved temperatures, the duration of heating has been fixed at four (04) hours. The oven that has served to that operation is of type Memmert (Figure 2). Once cooled down, small bricks are then submitted to tests of resistance to the universal press (Figure 4).

3. Results and Discussion

All results of identification tests of studied soil are presented in the annexes 1 and 2 (results of geotechnical tests (Figures 6-8; Table 2)).

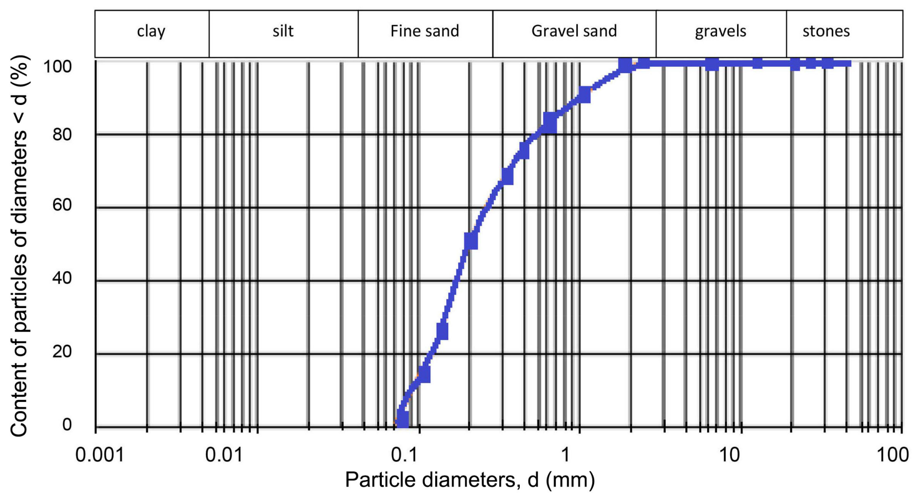

Figure 6. Granulometric curve of studied soil.

Table 2. Granular composition of the soil of Madingou.

Samples	% passing to sieve of soil µm	Maximal diameter (mm)	% clayes	% gravel sand	% gravelr
Soil of Madingou taken at a depth of 50 cm	90	3,5	60	17	25

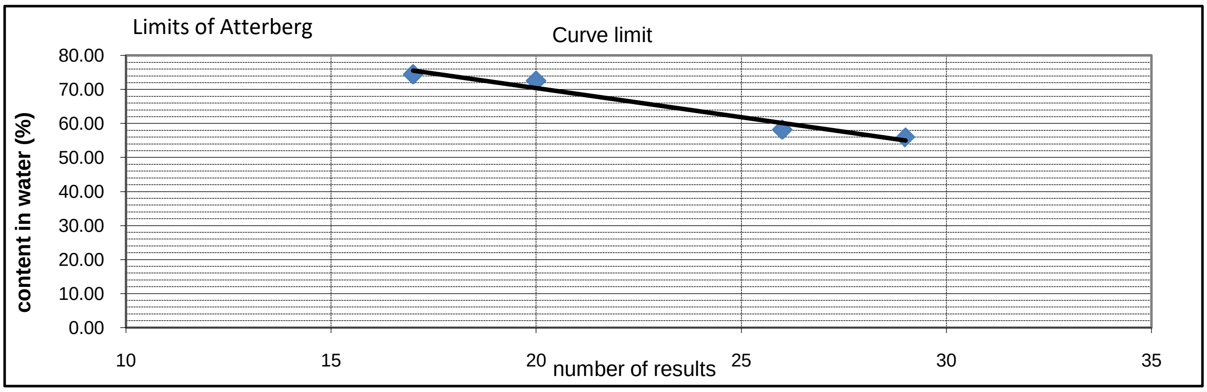

Figure 7. Results of limits of Atterberg.

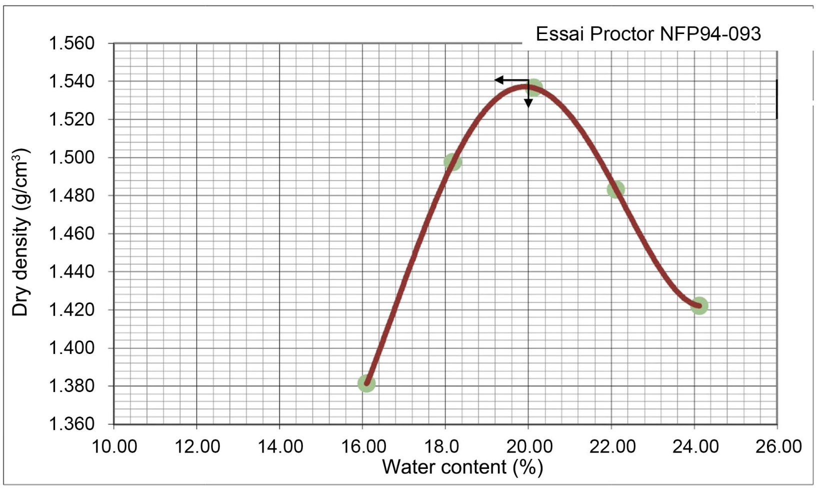

Figure 8. Courbe Proctor de la terre argileuse de Madingou.

3.1. Identification Tests of Material and of Classification of Raw Material

3.1.1. Granometric Analysis (NFP 945 – 056 of March 1996)

Figure 6 above points out that the soil of Madingou has a continued granulometry. From the appearance of this sieve, it is raised some information about the granular composition of this soil. The results on the granular composition are presented in the picture below. These results of the granulometric analysis by sieving show that our soil is composed of 60% of clay, 25% of gravel, and 17% of fine sand. The soil of Madingou possesses grains of which maximal diameter can exceed 3.5 mm at dry state, and there is the presence of grains of greater dimensions but these latter disintegrate in water.

The coefficient of the uniformity C_u is equals to 2.5 and the coefficient of curvature C_c = 0.9. The soil of Madingou has an opened out granulometry and it compacts well.

3.1.2. Limits of Atterberg (NF P11-300; NF P 94-051)

All results related to limits of Aherberg are presented on **Figure 8**.

- Limit of liquidity (W_L): 62%;

- Limit of plasticity (W_p) = 33.60%;
- Limit of plasticity (I_P) = 28.40%.
- Taking into account values of obtained properties, we can conclude that the soil is very plastic.

3.1.3. Proctor (NFP 94-093)

This test has given the presented results on the curve below (Figure 8).

The Proctor optimum is obtained at the point of coordinates (19.6%; 1.540 g/cm^3) for the making of none stabilized bricks (0%). Therefore, we have to wet the material with the content in optimal water found with the Proctor test. For this study, the added molasses into the clayey material gives a mixture which is difficult to mix. The results of other Proctor curves of the stabilized clay soil at 4%, 6% and 8% of molasses, the cassava starch and the molasses + the cassava starch are shortened in a Table 3.

Through results which are shown, we notice that small bricks made with the starch need more water than those made with the molasses, or molasses + starch. This is due to the fact that grains of the starch have a hydrophilic character.

3.1.4. Mechanical Resistance to the Small Bricks' Compression

The examination of the test tube after compression shows that the fissuring is parallel to the guidance of loading in the central area. This is due to the phenomenon of frying; it happens when the effort is well centered.

✓ **Resistances in compassion of stabilized clay small bricks to the molasses**

The analysis of Figure 9 shows the evolution of the resistances to the compression of small bricks, stabilized at molasses according to the fixed temperatures.

In all, we note an evolution of resistances to compression for temperatures going from 100˚C to 145˚C and a fall of resistances for temperatures varying from 145˚C to 200˚C.

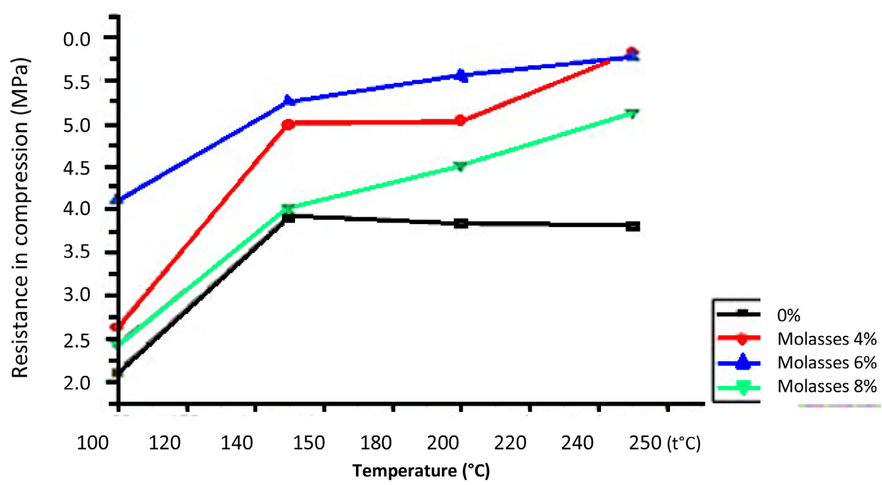

Figure 9. Evolution of the resistance in compression of clayey bricks, stabilized with sugar cane molasses, according to the temperature at different contents in molasses.

Table 3. Results of terms in optimal water and samples density.

Content (%)	Molassesstabilizer		Starch		Starch + Molasses	
	Y_d ($^t/_{m3}$)	W_{OPM} (%)	Y_d ($^t/_{m3}$)	W_{OPM} (%)	Y_d ($^t/_{m3}$)	W_{OPM} (%)
0	1.54	19.6	1.54	19.6	1.54	19.6
4	1.53	20.2	1.41	22	1.52	20.8
6	1.532	20.2	1.44	23.5	1.51	20
8	1.50	20	1.37	24	1.50	19.2

Thus, at 0% of molasses, the resistance in compression of small bricks, stabilized increases between 100˚C and 150˚C; it passes from 2.11 MPa to 3.92 MPa. In the contrary, from 150˚C to 250˚C, this resistance decreases of 3.92 MPa passing by 3.83 MPa to reach 3.81 MPa.

At 4% of molasses, we observe a strong growth of the resistance in compression from 100˚C to 150˚C with values comprised between 2.63 MPa to 4.98 MPa, and from 200˚C to 250˚C by values comprised between 5.03 MPa and 5.83 MPa.

At 6% of molasses, the resistance in compression of stabilized bricks increases between 100˚C and 250˚C with respective values of 4.10 MPa, 5.24 MPa, 5.57 MPa and 5.77 MPa.

At 8% of molasses, the resistance in compression of stabilized small bricks increases between 100˚C and 250˚C, passing by respective values of 2.44 MPa; 4.01 MPa; 4.45 MPa and 5.12 MPa. The stabilized bricks at 6% of molasses resist better. And, a brutal change for temperatures comprise in the interval of temperature situated between 200˚C and 250˚C. But, the dosage at 4% of molasses gives the biggest value of resistance from 5.82 MPa to 250˚C.

In effect, we notice that when the peak of temperature is reached, resistances are also maximals no matter the adopted formulation following different dosages in binder.

The analysis of **Figure 10** in the contrary shows the evolution of the resistance in compression of stabilized clay small bricks to the molasses, according to the content in molasses. The resistance in compression of stabilized small bricks to the molasses at 100˚C; 150˚C; 200˚C and 250˚C gives the same appearance between 0%; 4%; 6% and 8%.

At 100˚C, the resistance in compression of stabilized small bricks to the molasses respectively increases between 0%, 4% and 6% by passing at 2.11 MPa, 2.63 MPa and 4.11 MPa. Moreover, it decreases between 6% and 8% passing by points 4.11 MPa and 2.44 MPa. The same, between 150˚C and 250˚C, the resistance of stabilized small bricks to the sugar cane molasses respectively increases for dosages of 0%; 4%; 6% and 8% and respectively for values of 3.92 MPa, 4.98 MPa; 5.24 MPa and 3.83 MPa. Moreover, it decreases for dosages of 6% and 8% through values 4.01 MPa and 4.45 MPa. But, at 250˚C, the resistance in compression of stabilized small bricks with the molasses increases for dosages of 0% and 4% following values from 3.82 MPa to 5.82 MPa. It decreases for dosages 4% and 8% with respective values of 5.82 MPa; 5.77 MPa and 5.12 MPa.

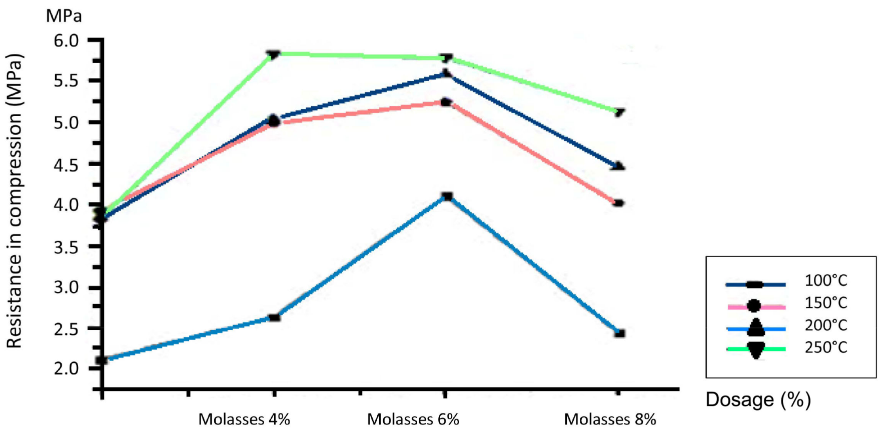

Figure 10. Evolution of the resistance in compression of stabilized clay bricks to molasses according to the content in molasses at 100˚C, 150˚C, 200˚C and 250˚C.

We notice that for soil concrete formulated at 8% of molasses, resistances in compression are minimized no matter the considered temperature for the heating.

We also notice that this clayey material contracts in a uniform way. The clay small bricks without molasses, lose quicker some interstitial water than those containing molasses. The dyeing change of clays of stabilized small bricks reveals that there has probably had an unexpected chemical reaction between the molasses and the clayey soil. This mechanical behavior can also be explained by the realized microstructural analysis [Malanda and al, 2022].

✓ **Resistance in compression of clay small bricks, stabilized with the cassava starch**

The analysis of Figure 11 and Figure 12 shows tendencies of the evolution of the resistance in compression of stabilized small brisks with the starch.

Thus, at 0% of starch, the resistance in compression of stabilized small bricks increases under temperatures of heating 100˚C and 150˚C. It passes from 2.11 MPa to 3.92 MPa. In the contrary, from 150˚C to 250˚C, this resistance decreases from 3.92 MPa until to reach 3.81 MPa. At 4% of starch, the resistance in compression increases for varying temperatures between 100˚C and 150˚C. It passes between 2.380 MPa and 2.912 MPa. Howerver, it decreases for varying temperatures from 150˚C and 200˚C passing by 2.912 MPa and 7.52 MPa. Finally, it decreases between 200˚C and 250˚C for values from 2.752 MPa and 3.135 MPa.

For dosages of 6% and 8% of starch, the resistance in compression small bricks decreases for temperatures of 100˚C and 250˚C through values of 2.952 MPa; 2.294 MPa; 2.275 MPa, 2.136 MPa and 2.523 MPa; 2.320 MPa; 2.223 MPa. Stabilized small bricks at 0% of starch in the contrary, better resist than those at 4%, 6% and 8%.

The analysis of Figure 14 shows the evolution of the resistance in compression of stabilized small bricks with starch, according to the content of this one but for varying temperatures between 100˚C; 200˚C and 250˚C. Between temperatures 100˚C and 150˚C, values of resistance in compression, reveal a decreasing of resistance to the compression of samples for dosages between 0% and 8% of starch. However, we notice the better appearance of the curve for dosages of 0% and 6% at different tempratures.

Here, the themo-mechanical behavior is moderate. Except the dosage at 0% of starch that is noticed and a regression of values of resistances under different temperatures, there is therefore a spreading of resistance values for dosages and formulations at 0%, 4% and 8%.

Figure 12, also shows that none stabilized small bricks (0%) resist better than stabilized small brick at 4%, 6% and 8% of starch. Then, we notice that as the temperature increases the mixtures containing more of starch give resistances in weak compression. Moreover, an excessive quantity of starch decreases the resistance of the small brick. However, it is essential to note that the usage of starch as a stabilizing in soils, remains complex because their volumic mass is very weak.

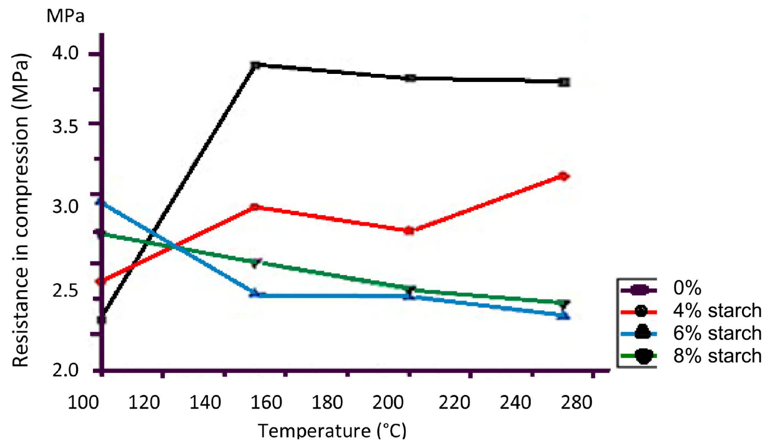

Figure 11. Evolution of the résistance in compression of stabilized clay bricks at cassava starch according to the temperature at different contents of cassava starch.

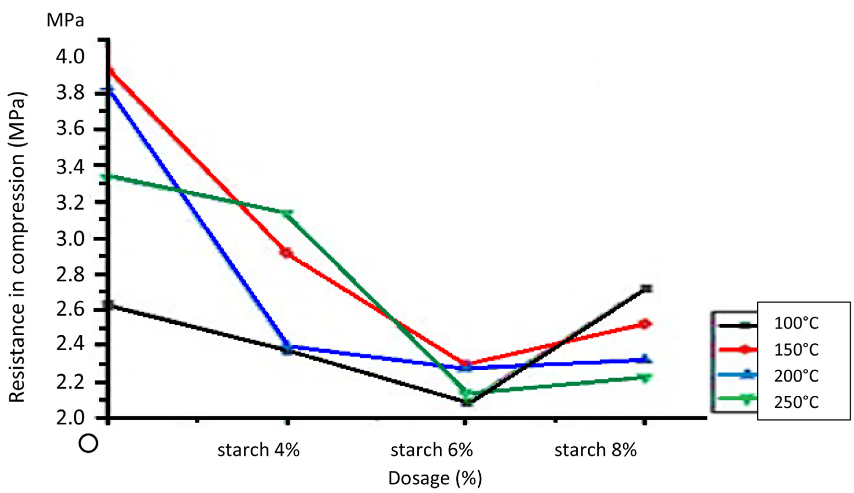

Figure 12. Evolution of the resistance to compressions of stabilized clay small bricks with the starch according to the dosage of the starch.

As often, the starch, at a given temperature can be a considerable contribution for the resistance but elsewhere, it decreases the resistance according to certain proportions.

This atypic behavior is the following of the swelling of starch grains because of temperatures of water absorption. The second domaine is characterized by a brutal fall of the resistance between temperatures 150˚C and 250˚C. Thus, the fall of resistances can be explained by means of qualitative and quantitative microstructural analysis.

The starch at 6% of dosage is less reactive between temperatures of 100˚C and 250˚C of heating temperature. Nevertheless, at 8% of dosage, the grain is at minima. We also consider that none stabilized small bricks (0%) resist better at 150˚C while between temperatures of 200˚C and 250˚C, they almost totally lose their rigidity.

- ✓ **Resistance in compression of stabilized clay bricks with (starch + molasses)**

The analysis of Figure 13 shows that at 0% of molasses + starch, the resistance in compression of stabilized bricks increases for temperatures of 100˚C and 150˚C, values are from 2.11 MPa to 3.92 MPa. However, this resistance respectively decreases between 150˚C, 200˚C and 250˚C for values of 3.83 MPa, 3.83 MPa and 3.33 MPa.

- At 4% of molasses + starch, the resistance in compression of stabilized bricks respectly increases for temperatures 100˚C, 150˚C and 200˚C; 250˚C for values from 2.63 MPa to 4.52 MPa and from 3.63 MPa to 3.92 MPa. However, this resistance decreases for temperatures from 150˚C and 200˚C passing from 4.52 MPa to 3.63 MPa.

- At 6% of molasses + starch, the resistance in compression increases for 100˚C, 150˚C, 200˚C; 250˚C, respectively passing from 4.3 MPa to 4.72 MPa and from 3.63 MPa to 3.92 MPa. But, this resistance decreases for temperatures 150˚C and 200˚C passing from 4.72 MPa to 4.68 MPa.

- At 8% of molasses plus starch, the resistance of stabilized brick increases. It passes from 2.44 MPa to 4.89 MPa. Moreover, this resistance respectively decreases between 150˚C, 200˚C and 250˚C and gives temperatures of 4.89 MPa; 4.46 MPa and 4.63 MPa.

- Nevertheless, the content at 6% (starch + Molasses) gives the greatest value of resistance, as 5.31 MPa and 250˚C.

The analysis of Figure 14 shows the evolution of the resistance of stabilized clay bricks to the starch + molasses. The values of resistances, at 200˚C and 250˚C of starch + molasses and the witness brick at 0% puts up the same appearance. Here, curves decrease between 0% and 4%, followed by an increasing evolution between 6% and 8%, then, puts up the tendencies between 6% and 8% of molasses + starch. In the contrary, at 150˚C, the values of resistances in compression increase of 0% to reach 8% of molasses + starch and decreases between 6% and 8%.

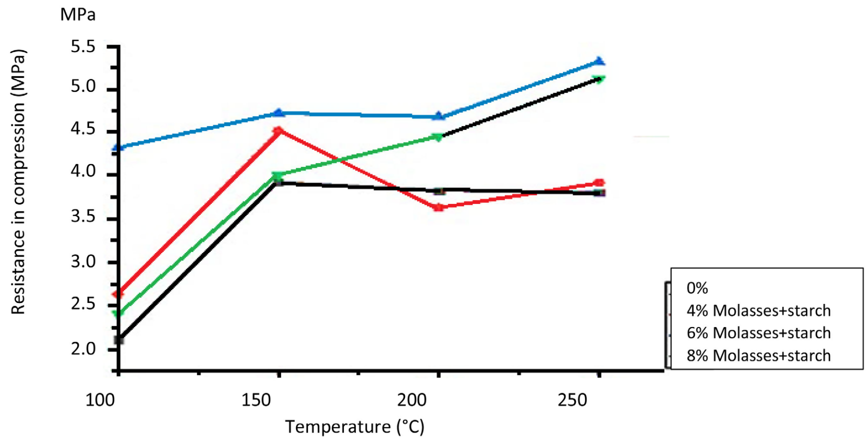

Figure 13. Evolution of the R_c of bricks in AS to the starch + M, according to the temperature at different content in M + starch.

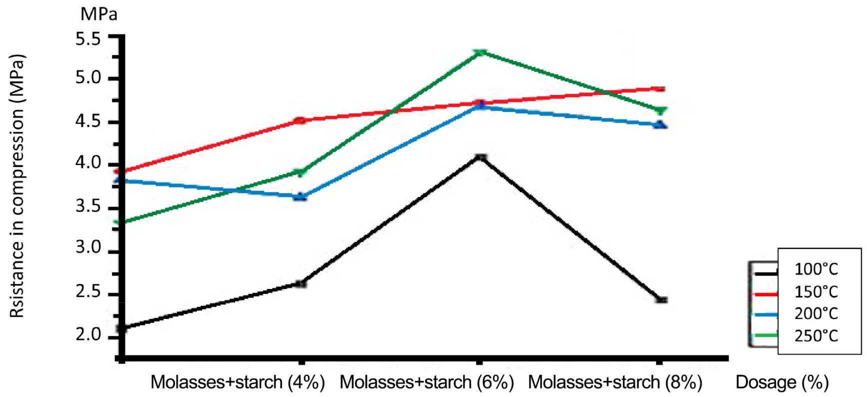

Figure 14. Evolution of the resistance in compression of stabilized clay bricks with the cassava starch + molasses, According to the content in starch + molasses to 100˚C, 150˚C, 200˚C and 250˚C

3.1.5. Improvement of Resistances in Compression of Stabilizing

Table 4 shows the improvement of different stabilizings used in making small bricks.

In short, by stabilizing with the molasses and the starch, we have obtained values of small bricks more resistant than none stabilized small bricks (0%). During the test of compression, small bricks break without cutting, so, the starch maintains pieces between them. The mixture (molasses + starch) is revealed as the ideal binder for this stabilization of small bricks intended to the construction of residence buildings (**Table 4**). This is justified by the fact that the structural matrix of small bricks is modified in reducing pores, in reserving particles one another. This cohesion between particles inside the improved matrix the resistance to the compression and the material texture. We pass therefore from a ventilated matrix to a more compact matrix, excepted the saturation of pores.

3.1.6. Statistic Analysis of Resistance by Temperatures Level

Table 5 presents the evolution of the resistance of stabilized small bricks according to the level of the temperature.

Table 4. Improvement of resistances in compression.

Content in stabilizings (%)	R_c (0%)	Molasses		Cassava starch		Starch + Molasses		Technical performances comprised soil bricks according CRATERRE	
		$R_{C\max}$ MPa	Improvement (%)	$R_{C\max}$ MPa	Improvement (%)	$R_{C\max}$	Improvement (%)	Type 1	Type 2
4	3.92 Mpa	5.82	32.65	3.13	No improvement	4.52	13.27	2 MPa	2 à 4 MPa
6		5.77	32.06	2.95		5.31	26.17		
8		5.12	23.43	2.72		5.12	23.04		

It comes out from our results that the increasing of temperature has not at all improved the middle resistance of stabilized bricks to starch.

In the contrary, as far as stabilized small bricks to the molasses are concerned, we notice a significant improvement of the resistance in compression of small bricks when the temperature passes from 100˚C to 150˚C or from 200˚C to 250˚C. In effect, space values of confidence sufficiently proves that there is more chance (in 95% of cases) in middle, the resistance in comprehension changes between these temperatures. However, it is noticed that between 150˚C and 200˚C, the middle resistance in compression of stabilized clay bricks to the molasses remains unchangeable in the contrary, in mixing both binders (molasses + starch).

We notice that in the temperature passing 100˚C, the resistance in compression significantly increases. Starting from 150˚C, the increasing of the temperature has no longer effects on the resistance at the level of 5%. In other words, it is noted that after 150˚C, the temperature no longer affects the resistance in compression of stabilized clay bricks to the molasses (Table 5).

Thus, the results of our analyses according to the temperature also inform us that, stabilized bricks to the starch are less resistant than those stabilized to the molasses. This is true when the temperature is superior or equals to 150˚C. At 100˚C, there is no significant difference.

3.1.7. Statistic Analysis According to the Dosage in Binders

The analysis according to the content in starch reveals that the increasing of the content of that product diminishes the level of the resistance in compression. However, this diminution is not important at the level of 5%.

It also comes out of obtained results that there is an important difference between the resistance of none stabilized small bricks and those stabilized to the molasses. Once small bricks are stabilized, we no longer need to increase its content because this increasing does not affect the resistance.

In increasing the content of mixture of both products (starch + molasses), we notice that there is no significative change between stabilized small bricks to a unique binder and those stabilized to both binders (Table 6).

Therefore, the analysis by comparison reveals that once stabilized bricks, those that contain the molasses are more resistant than those of starch. On the contrary, there is a distinct improvement of the resistance of bricks with the binder molasses + starch.

Table 5. Evolution of the resistance of stabilized clay bricks according to the temperature level.

Temperature/binders		100˚C	150˚C	200˚C	250˚C	Altogether
Starch	Middle	2.54	2.91	2.79	2.84	2.77
	Confidence space	[2.26 - 2.82]	[2.5 - 3.33]	[2.4 - 3.18]	[2.36 - 3.32]	[2.37 - 3.18]
Molasses	Middle	2.73	4.38	4.29	5.14	4.14
	Confidence space	[2.25 - 3.21]	[4.14 - 4.62]	[3.89 - 4.69]	[4.73 - 5.55]	[3.38 - 4.9]
Starch + Molasses	Middle	2.86	4.31	4.15	4.33	3.92
	Confidence space	[2.36 - 3.37]	[3.9 - 4.73]	[3.74 - 4.56]	[3.76 - 4.91]	[3.32 - 4.51]

Table 6. Evolution of the resistance of stabilized clay small bricks according to the level of content in binder.

Temperature/binders		0%	4%	6%	9%	Altogether
Starch	Middle	3.43	2.79	2.41	2.45	2.77
	Space	[2.99 - 3.88]	[2.48 - 3.11]	[2.1 - 2.73]	[2.24 - 2.66]	[2.37 - 3.18]
Molasses	Middle	3.43	4.34	4.76	4.02	4.14
	Space	[2.99 - 3.88]	[3.90 - 4.78]	[3.96 - 5.56]	[3.92 - 4.12]	[3.38 - 4.9]
Starch + Molasses	Middle	3.43	3.48	4.76	3.98	3.92
	Space	[2.99 - 3.88]	[2.95 - 4.01]	[4.36 - 5.16]	[3.36 - 4.61]	[3.32 - 4.51]

4. Discussion

Many research works have been carried out in the frame of the stabilization of bricks from raw soil (BTC). Studies realized by Mango, (2019), Meukam (2004), P'ka (2002) [8] [10] Talla (2010), Ouédraogo (2019), Tamba and al (2017) [5] [9] [15] [22] and others, give the evidence of a consequent improvement of mechanical properties of soil bricks Barro (2009) compressed thanks to the contribution of binders [23]. Moreover, works of Boffoué and al (2015), Ratrimoarisonina (2021), Babe and al (2020), show that the contribution of a binder as stabilizing improves thermo-mechanical properties of those stabilized bricks, [24] [25] [26].

In effect, obtained results in the frame of this work evidence a relation between mechanic resistance to the compression at different dosages of binders and of heating under different temperatures. But, this relation in the small bricks behavior under loading differs according to used binder and of the temperature of fixed heating.

By the way, this is explained and justified by the intensity of the modification not only of physic-chemical connection (clayey mixture + binders between clay packs), but also the modification of material properties that constitute cementary matrix.

In effect, studies carried out by Boffoué and al (2015) on the determination of themo-mechanical parametres of comprised clay blocs and stabilized with cement show that the addition of cement has certainly improved the mechanic resistance and the thermic conductivity, but the production of cement enormously contributes to the climatic heating by emitting tones of carbone dioxide [24]. However, research works by Engy and al (2021), as Moussa and al (2016), or Mohamed (2022), [2] [3] [27] show that the usage of flying ashes activities by alkalises and of dairy of high granuled furnace molding or other binders as substituting of cement have considerably improved thermo-mechanical properties of small bricks and are promising for sustainable constructions [2] [3] [27]. These results are in coherence with those obtained by the stabilization with the molasses or with the binder (molasses + starch), in the frame of this study.

Moreover, Ratrimoarisonina (2021) has shown that heated bricks and tested at the residual state (after cooling) negatively modify some thermo-mechanical properties. This is justified in cases of the formulations of these concretes of soil with the starch binder of which obtained results are much disproportionate [25].

In the same way, Babé and al (2020) have worked on the thermo-mechanical characterization and the durability of reinforced adobes of mil waste fibres [26]. This research work has shown that the mil fibres, contribute to the improvement of the mechanical and thermic resistance at about 38 and 23%. This is also in coherence with obtained results with the stabilization with the molasses or the mixture (starch + molasses).

On the whole, these results suggest that the molasses appears as the best in the optimization of the formulations and, consequently, this one contributes better to the improvement of thermo-mechanical performances of stabilized small bricks. Besides, this is justified in research works of Malanda and al (2022), in the microstructural behavior, and in coherence with works by Lima and al (2012), [13] [20].

Research works by Ngouama (2008) have shown that incorporated starch in the clay, for a porcentage of fines comprised between 30 to 100%, also reaches good resistances in compression and improves in fact mechanical properties of stabilized bricks [17]. Marcedo de Souza and al (2021) have also shown the efficiency of the cassava starch binder in the stabilization of small bricks in raw soil [16]. But, rare are studies carried out for the determination of thermo-mechanical properties. We therefore note that our results are not very convincing.

So, we can note that obtained results after crushing and heating with the molasses binder, being better compared with the starch show well certainly superior values, are significatively in accordance with the norme issued by CRA-terre [15] [20] and [22], and also better than those obtained by Talla (2010).

Moreover, we can note that risks of fissuring linked to constraint generated in the elementary matrix and the necessity microstructural a predictive model that can evaluate the behavior of stabilized material following different dosages of binders.

There is also an influence in the constituted elementary matrix by each formulation, of the density of the binder in comparison with poral network of each formulated concrete.

The multi ladder nature of the material in the basis of molasses, the cassava starch, or again molasses + starch, and the complexity of the study of phenomenon linked to the thermo-mechanical raises some interrogations on the most suitable manner to create a realist model.

5. Conclusion

This experienced study has allowed us to precise first the geotechnical nature of the soil in the known place through a geotechnical characterization before the formulation of concrete with soil. Thus, the revealed clay class is of type of A_3 (very plastic soil) according to the classification GTR. For that, stabilized small bricks have been dried at different temperatures (100˚C, 150˚C, 200˚C and 250˚C) and with organic binders (molasses, starch, molasses+ starch) following different dosages at 4%, 6% and 8%. Mechanic properties are determined by tests of compression after heating at different temperatures (thermic properties). Experimental results positively show that resistances in compression of stabilized small brackets with the help of the molasses are in correlation with the dosage in binder (stabilizing). However, it is negative compared with the starch and enough positive with the mixture (molasses + starch), this is when the temperature is at 150˚C. But, at 100˚C, the difference is not significative. From all the formulations of concrete of realized soil, the dosage at 6% of binder (stabilizing) seems to be the best in seeing of values of obtained resistances after heating. Other tracks of research are also envisageable to establish the link between cemented matrix of concrete of constituted soil and the microstructural analysis. The usage of these bricks can lead, with an appropriated architectural according to the climate, to contribute, to reduce not only the load of construction but a better thermic comfort. This can be an interesting contribution in the frame of the reduction of green house effects in the construction materials.

Conflicts of Interest

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

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Annexe

Annexe 1. Results of Measure of Mechanical Properties

Results of measures carried out are recorded in below

The resistance in compression of stabilized clay bricks at cassava starch (MPa)								
Content of stabilizings (%)	**100˚C**		**150˚C**		**200˚C**		**250˚C**	
	2.202		3.761		3.701		3.503	
0%	1.902	2.113 ± 0.33	3.868	3.929 ± 0.39	4.102	3.936 ± 0.39	4.201	3.812 ± 0.31
	2.23		4.158		3.678		3.891	
	1.98		3.073		2.085		2.189	
4%	2.592	2.380 ± 0.61	3.143	2.912 ± 0.62	2.981	2.752 ± 1.11	3.270	3.135 ± 0.76
	2.568		2.52		3.19		3.946	
	2.334		2.155		2.123		1.972	
6%	3.120	2.952 ± 1.07	3.11	2.294 ± 1.5	2.40	2.275 ± 0.28	2.800	2.136 ± 0.83
	3.402		1.617		2.302		1.636	
	3.023		2.938		1.962		2.144	
8%	2.033	2.726 ± 1.09	2.180	2.523 ± 0.75	2.430	2.320 ± 0.6	2.172	2.223 ± 0.21
	3.122		2.451		2.568		2.353	
The resistance in compression of stabilized clay bricks at molasses (MPa)								
	2.202		3.761		3.701		3.503	
0%	1.902	2.113 ± 0.33	3.868	3.929 ± 0.39	4.102	3.836 ± 0.42	4.201	3.812 ± 0.31
	2.230		4.158		3.687		3.891	
	2.440		5.079		4.809		5.444	
4%	2.282	2.633 ± 0.36	3.920	4.980 ± 1.15	4.702	5.033 ± 0.54	5.70	5.820 ± 0.83
	2.087		4.019		5.240		6.32	
	3.670		5.445		6.107		6.736	
6%	4.461	4.110 ± 0.79	5.133	5.240 ± 0.31	4.99	5.570 ± 1.12	5.490	5.121 ± 1.29
	4.200		5.142		5.615		5.090	
	1.920		4.000		4.242		4.970	
8%	2.600	2.442 ± 0.88	4.202	4.011 ± 0.37	3.987	4.503 ± 1.29	4.550	5.121 ± 1.29
	2.806		3.833		5.273		5.843	
The resistance in compression of stabilized clay bricks. the molasse + the cassava starch (MPa)								
	2.202		3.761		3.701		3.503	
0%	1.902	2.113 ± 0.33	3.868	3.929 ± 0.39	4.102	3.836 ± 0.42	4.201	3.812 ± 0.31
	2.230		4.158		3.687		3.891	
	2.888		3.880		2.638		2.189	
4%	2.232	2.633 ± 0.65	4.443	4.525 ± 1.44	4.281	3.639 ± 0.42	3.270	3.135 ± 1.76
	2.72		5.329		3.981		3.946	
	3.917		5.495		3.995		5.070	
6%	4.40	4.323 ± 0.74	5.097	4.721 ± 1.91	4.192	4.686 ± 1.88	5.330	5.314 ± 0.46
	4.652		3.591		5.871		5.537	
	2.295		4.991		4.376		4.369	
8%	2.640	2.401 ± 0.37	4.120	4.01 ± 1.8	4.802	4.450 ± 0.63	4.923	5.120 ± 1.16
	2.278		3.019		4.172		5.79	

Annexe 2. Resultats of Geotechnic Tests of Taken Materials

Recapitulative picture of tests		Sample		
Project				
Deep (m)				
Nature of soils		Material1	Material2	Material3
Content in natural water	W%	5	5	5
Granulometric analysis (% passings)	Dmax (mm)	20	0	0
	5 mm	100	100	100
	2 mm	76.0	76.0	78.0
	80 µm	2.0	3.0	2.0
Value in blue of methylene		0.07	0.33	0.33
Content in M.O. (%)		8.00		
Specific weight		2.240		
Appearente density (t/m^3)		1.015		
Classification GTR		A2	A2	A2
Proctor	γs (t/m^3)	1.600	1.571	1.540
	Wopm (%)	20.60	20.20	22.00
CBR	γd (95% OP)	1.520	1.492	1.463
	CBR Immediate	7	40	45
	CBR Immersion	39	50	55
	Swelling (%)	0.040	0.020	0.006
Simple Compression (Rc in Mpa)	7 days	1.16	1.45	1.50
	28 days	1.40	1.74	2.31
Traction by flexion (Rtf in Mpa)	7 days	0.45	0.52	0.58
	28 days	0.53	0.67	0.78
Absorption n (%)			17.53	11.69