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Improvement of Compressed Earth Brick Properties by Stabilization with Combined Cement and Rice Fibers

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ABSTRACT

In the present article, the effect of combined rice biomass and cement stabilization on the mechanical and thermal properties of compressed earth blocs are analyzed. The considered stabilizers are rice straw, rice husk and cement. A previews study highlighted the effect of the individual stabilizer on both mechanical and thermal properties was determined. In fact, it was shown that cement stabilization highly increases the mechanical properties but it has negative impact on the insulation performance of the bloc. In the other hand, the rice fibers (straw and husk) improve both the insulation performance and the mechanical properties but the increase in mechanical properties is not significant with respect to that observed with cement. Then, in this study, we analyze the impact of combining rice fibers and cement as stabilizers in the compressed bricks. The results show that the combination of rice fibers and cement in some proportions allows to significantly improve both mechanical properties and insulation performance of the soil bricks.

Keywords: Compressed soil brick, rice fibers stabilization, local construction materials, mechanical properties, insulation performance.

1. Introduction

Nowadays, the need for each country to use or locally transform its raw materials is a necessity. In the construction domain, many African societies adopted new construction technics, particularly those of western inspiration. Not only the technics are imported but also the building materials. The consequences are that several countries are significantly dependent to imported construction resources and the buildings are not adapted to the local climate. In Burkina Faso for example, the energy consumption of public sector buildings related only to thermal comfort is estimated at 30,000 MWh/year in 2003, with a financial cost of nearly 3,4 billion FCFA/year [1] and it represents more than 35% of the total energy consumption of this sector. In a global context, marked by an energy deficit, climate change, strong population growth and major environmental issues, rational management of resources becomes necessary [2, 3]. The need to use local materials in suitable building architectures becomes one of the effective solutions to promote. Several technics have been developed to improve local accessible resource for building [2, 4, 6, 11]. The use of biomass as stabilizers of soil bricks is one of the widespread technics. In [2], rice husk, rice straw and cement were individually used to stabilize compressed soil bricks. In fact, it is shown that cement stabilization highly increases the mechanical properties but it has negative impact on the insulation performance of the brick. In the other hand, the rice fibers (straw and husk) improve both the insulation performance and the mechanical properties but the increase in mechanical properties is not significant with respect to that observed with cement. The objective of this study is to analyze the impact of combining rice fibers and cement as stabilizers on the mechanical and thermal properties of compressed soil bricks.

2. Material and Method

2.1 Selection of the earth

The soil was chosen taking into account the recommendation on rate in mass of clay content ranging from 5% to 30% [6, 7, 8] to ensure good cohesion of the particles and facilitate the compression of the blocks. We chose earth from the quarry of the Zi-matériaux company located in the rural commune of Loumbila, in the center of Burkina Faso. Sieving and sedimentometry tests are run on a sample of the soil according to the respective standards NF P18-560 and NF P94-057.

2.2 Stabilizers

2.2.1 Cement

In the reference [2], we used SUPER CPA45 CEM II/B-M 42.5R cement, made in Burkina Faso by CIMAF (Ciments de l'Afrique) in accordance with Burkina Faso standard NBF 02-013:2009. The choice of this cement is based on the fact that is a high-quality cement locally available in the market. In [2], it shown that the addition of 2% by mass of cement to the chosen soil already guarantees satisfactory mechanical properties. Besides, more the rate by mass of cement in the compressed soil brick, higher the increase in mechanical properties of the brick but, worse the insulation performance of the brick. For all the above raison, we decide to only consider 2% by mass of cement stabilization in the compressed soil bricks in this study.

2.2.2 Rice straw and rice husks

In our previews study [2], it is shown that rice straw and husks, individually, improve significantly the insulation performance of the compressed soil bricks. Rice straw represents the remaining stalks and leaves after the grains are harvested. It is the significant portion of the rice biomass. Rice husks are the protective coverings of rice grains. Rice straw was air-dried and ground to obtain particles smaller than 1 cm. Rice husks were also ground to obtain particles smaller than 2 mm. Samples of compressed soil bricks were made with addition of 1%, 2% and 4% by mass of rice straw. Samples were also made with addition of 1%, 2% and 4% by mass of rice husks. In one hand, the thermal tests show a decrease in thermal conductivity of 29.6 %, 31 % and 41.6 % respectively for 1%, 2% and 4% by mass of rice straw. In the other hand, the same tests show a decrease in thermal conductivity of 8 %, 11 % and 14 % respectively for 1%, 2% and 4% by mass of rice husks. These results are also in agreement with the study of [9, 10, 11, 12, 13].

2.3 Choice of stabilizers combination rate

It is reminded that the aim of this work is to propose optimized ratio by mass of rice fibers and cement as stabilizers that lead to compressed soil bricks with optimal mechanical and insulation (thermal) properties. Based on the results presented in the preview section, the samples formulations proposed in

Table 1 will help to analyze the impact of combining rice straw, rice husks and cement in the bricks and to see if it leads to a significant improvement of both mechanical and insulation performance.

2.4 Compressed soil bricks production process

The method of manufacturing the compressed soil bricks begin by making a mixture with the quantities of soil and stabilizers according to the proportions indicated in Table 1. This mixture is stirred manually until getting a homogeneous mixture. Next, water is gradually added and the whole is kneaded by hand (for at least 10 minutes) until a slightly damp, homogeneous paste is obtained. A mold is filed with this paste which is finally compacted in a manual press such as the TERSTARAM model, Figure 1. After compaction, the brick is immediately removed from the mold and is stored in a shed, away from sunlight, to prevent excessive drying, which could lead to cracks. Figure 2 shows examples of bricks samples after drying. The dimensions of each brick are: 4 cm x 4 cm x 16 cm.

2.5 Mechanical characterization of bricks

The mechanical characteristics measured for each sample are the compression and bending strengths.

2.5.1 Compression strength tests

A half-block of each sample of brick is used to perform compression test on a CONTROLAB-type automatic machine, Figure 3. The tests are made in accordance with European Standard EN 196-1. The magnitude of the compression strength R_c is given by formula (1).

$$R_c = \frac{F}{S} \qquad (1)$$

Where :

R_c: Compressive strength (MPa);

F: maximum crushing force of the sample (N)

S: area of application of the force (mm^2)

2.5.2 Three-point bending strength tests

To measure the three-point bending strength, an increasing bending force is applied on the whole brick using an automatic machine until the brick completely ruptures, Figure 4.

2.6 Thermal characterization

The device KD2-Pro, Figure 5, is used for measuring the thermal properties of the bricks such as thermal conductivity, thermal diffusivity and specific heat capacity. The device uses the approach proposed by Carslaw and Jaeger [14] which uses the transient linear heat source method to evaluate parameters.

3. Results and Discussions

3.1 Mechanical tests results

3.1.1 Compression strength results

Table 2 shows the results of the compression strength tests carried on the different bricks samples after thirty (30) days of curing. It is noted that adding only 2% of cement by mass of the soil brick increases the compression strength by 62%. This increase in compression strength is confirmed by works mentioned in the literature [2, 8, 14, 15, 16]. If we keep the proportion of cement at 2% and add rice husks (2 or 4%), the compression strength decreases significantly even though, it remains greater than the one of the bricks made of soil exclusively. But, Table 2 shows that 4% of rice straw allows to balance the lost in compression strength. In fact, the compression strength with this last formulation is almost the same as the one of the bricks stabilized with 2% of cement exclusively. Besides, the formulation that combines rice husks and rice straw in an equal proportion provides a slightly higher compression strength.

3.1.2 Bending strength results

Table 3 presents the results of the bending strength tests of the various formulated earth bricks after 30 days of curing. It can be remarked that the trend of the bending results is same as for the compression one. In fact, the stabilization with 2% of cement alone significantly increases the bending strength by 73%. The fact of adding rice fibers (rice husks or/and rice straw) decrease this bending strength. The formulation that combines rice husks and rice straw in an equal proportion (in addition to the 2% of cement) allows to quickly balance the lost in bending strength. In fact, Table 3 shows that adding 2% of rice husks and 2% of rice straw provides bricks with bending strength 87% greater than the one of bricks with soil exclusively. It is remembered that the cement acts as a hydraulic binder, thus improves the cohesion and the capacity to resist bending and compression stresses.

3.2 Thermal characterization results

Table 4 and Table 6 show that the values of the main thermal parameters which are related to the insulation performance of a building material (thermal conductivity, volumetric heat capacity, thermal diffusivity), significantly increase when only 2% of cement is added. However, the incorporation of rice fibers decreases the same parameters. In fact, if 4% of rice straw is added in combination with the cement (2%), the thermal conductivity decreases by 7% when it is compared to the reference brick (brick made of soil exclusively), Table 5. It can also be noticed that the rice straw has significant effect on the thermal conductivity than rice husks. It is remembered that lower values of the above-mentioned thermal parameters suggest better insulation against heat et moisture propagation through the brick. Table 4 also shows that the density of the compressed bricks decreases as the rate of the biomass stabilizer (rice husks or/and rice straw) increases. All the compressed bricks have the same dimensions and consequently the same volume. The density of the biomass being lower than that of the earth, then the density of the entire brick decreases as the portion of biomass increases. Besides, in the construction domain, the compression strength and the thermal conductivity are the parameters which are checked in priority when it comes to analyze the mechanical and insulation performance of a brick [2, 17, 18, 19, 20]. In Table 6, the compression strength and the thermal conductivity of the different samples of compressed soil bricks are presented. All the samples have the same portion of cement (2% by masse). We can underline that rice straw and combination of rice straw and rice husk (in equal proportion) are the two formulations that highly increase compression strength. However, while considering insulation performance (lower value of the thermal conductivity), the combination of rice straw and rice husk (in equal proportion) is the best formulation and then comes the stabilization with rice straw, Table 7.

4. Conclusion

In this work, several investigations are done in order to propose formulations of compressed soil bricks stabilized with combination of cement and rice fibers and which presents significant improvement of both mechanical properties and insulation performance. In fact, a previews study shows that cement highly improve the mechanical properties of the bricks but it degrades the insulation performances. In the other hand, rice fibers improve the insulation performance but their improvement of the mechanical properties is limited.

Our investigations in this study allow to propose bricks formulations that lead to the improvement of both mechanical and insulation performance. In fact, it is shown that:

- stabilization with cement in combination with rice straw and rice husk (in equal proportion by mass) leads to better compromise in improvement of both mechanical and insulation (thermal) performances of the bricks
- stabilization with cement and rice straw is an alternative formulation that also leads to significant improvement of both mechanical and insulation performances of the bricks.

Further study could focus on modelling and simulating a typical building made of compressed soil bricks according to the above-mentioned formulation in order to determine the energy consumption and the quality of the building interaction with its environment

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Figures

Figure 2: Picture of the manual press used for manufacturing the bricks

Figure 1: Picture of brick sample

Figure 4: Compression machine

Figure 3: KD2-Pro device

Tables

Table 1: Formulation of compressed soil brick samples

Formulation	Stabilizers rate (in % by mass)			
	Soil	Rice husk	Rice straw	Cement
Soil	100	0	0	0
Soil - Cement	98	0	0	2
Soil - Rice husk - Cement	98	2	0	2
	96	4	0	2
Soil - Rice straw – Cement	98	0	2	2
	96	0	4	2
Soil - Rice straw – Rice husk - Cement	98	1	1	2
	96	2	2	2

Table 2: Compression strength test results

Formulation	Stabilizer rate (in % by mass)				Compression Strength R_c (MPa)	Compression Strength Comparison
	Soil	Rice husk	Rice straw	Cement		
Soil	100	0	0	0	2,021 ± 0,08	100%
Soil - Cement	98	0	0	2	3,271 ± 0,340	162%
Soil - Rice husk - Cement	98	2	0	2	2,834 ± 0,078	140%
	96	4	0	2	2,971± 0,091	147%
Soil - Rice straw – Cement	98	2	0	2	3,063 ± 0,357	152%
	96	4	0	2	3,372± 0,271	164%
Soil - Rice straw – Rice husk - Cement	98	1	1	2	3,125 ± 0,184	155%
	96	2	2	2	3,425± 0,217	167%

Table 3: Bending Strength test results

Formulation	Stabilizer rate (in % by mass)				Bending Strength R_f (MPa)	Bending Strength Comparison
	Soil	Rice husk	Rice straw	Cement		
Soil	100	0	0	0	0,206 ± 0,014	100%
Soil - Cement	98	0	0	2	0,356 ± 0,035	173%
Soil - Rice husk - Cement	98	2	0	2	0,291 ± 0,013	141%
	96	4	0	2	0,305± 0,012	148%
Soil - Rice straw – Cement	98	0	2	2	0,319 ± 0,014	155%
	96	0	4	2	0,339± 0,011	165%
Soil - Rice straw – Rice husk - Cement	98	1	1	2	0,338 ± 0,023	164%
	96	2	2	2	0,385± 0,031	187%

Table 4: Density, Thermal conductivity and Volumetric heat capacity

Formulation	Stabilizer rate (% by mass)			Test Temperature (°C)	Density	Thermal conductivity	Volumetric heat capacity
	Rice husk	Rice straw	Cement		P (kg.m^{-3})	λ (W.m^{-1}.K^{-1})	Cv (MJ.m^{-3}.K^{-1})
Soil	0	0	0	38	1906,55	0,517 ±0,002	2,065 ± 0,0019
Soil – Cement	0	0	2	35,8	1856,36	0,571 ± 0,0019	2,618 ± 0,0025
Soil - Rice husk - Cement	2	0	2	35,09	1839,09	0,556 ± 0,0018	2,399 ± 0,0016
	4	0	2	35,09	1817,59	0,54 ± 0,0017	2,469± 0,0018
Soil - Rice straw – Cement	0	2	2	36,05	1768,18	0,529 ± 0,0026	2,501 ± 0,0020
	0	4	2	36,05	1738,98	0,483± 0,0021	2,561± 0,0018
Soil - Rice straw – Rice husk - Cement	1	1	2	37,69	1876,55	0,549 ± 0,0018	2,536 ± 0,0017
	2	2	2	37,69	1850,55	0,528± 0,0018	2,591± 0,0014

Table 5: Formulation effect on thermal conductivity of the bricks

Formulation	Stabilizer rate (% by mass)			Thermal conductivity λ ($W.m^{-1}.K^{-1}$)	Thermal conductivity comparison
	Rice husk	Rice straw	Cement		
Soil	0	0	0	0,517 ± 0,002	100%
Soil – Cement	0	0	2	0,571 ± 0,0019	110%
Soil - Rice husk - Cement	2	0	2	0,556 ± 0,0018	108%
	4	0	2	0,54 ± 0,0017	104%
Soil - Rice straw – Cement	0	2	2	0,529 ± 0,0026	102%
	0	4	2	0,483± 0,0021	93%
Soil - Rice straw – Rice husk - Cement	1	1	2	0,549 ± 0,0018	106%
	2	2	2	0,528± 0,0018	102%

Table 6: Specific heat capacity, Thermal diffusivity and thermal effusivity

Formulation	Stabilizer rate (% by mass)			Test Temperature (°C)	Specific heat capacity	Thermal diffusivity	Thermal effusivity
	Rice husk	Rice straw	Cement		C_P (kJkg^{-1}.K^{-1})	α (10^{-7} m^2.s^{-1})	E (J.s$^{-1/2}$.m^{-2}.K^{-1})
Soil	0	0	0	38	1,083 ± 0,0010	2,097 ± 0,0017	1032,99 ± 2,14
Soil – Cement	0	0	2	35,8	1,411 ± 0,0013	2,353 ± 0,013	1222,65 ± 2,18
Soil - Rice husk - Cement	2	0	2	35,09	1,304 ± 0,0009	2,313 ± 0,0016	1154,92 ± 1,70
	4	0	2	35,09	1,921± 0,0012	2,230± 0,0011	1152,42 ± 1,62
Soil - Rice straw – Cement	0	2	2	36,05	1,414 ± 0,0013	2,330 ± 0,0019	1150,23 ± 2,28
	0	4	2	36,05	1,482 ± 0,0016	2,287± 0,0016	1097,23 ± 1,78
Soil - Rice straw – Rice husk - Cement	1	1	2	37,69	1,352 ± 0,0009	2,310 ± 0,0012	1180,00 ± 1,75
	2	2	2	37,69	1,411± 0,0009	2,262± 0,0012	1157,00 ± 1,72

Table 7: Formulation effect on Compression strength and Thermal conductivity

Formulation	Stabilizer rate (% by mass)			Comparison	
	Rice husk	Rice straw	Cement	Compression Strength R_c	Thermal conductivity λ
Soil	0	0	0	100%	100%
Soil – Cement	0	0	2	162%	110%
Soil - Rice husk - Cement	2	0	2	140%	108%
	4	0	2	147%	104%
Soil - Rice straw – Cement	0	2	2	152%	102%
	0	4	2	167%	93%
Soil - Rice straw – Rice husk - Cement	1	1	2	155%	106%
	2	2	2	169%	102%