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Characterization of Stabilized Earth Blocks with Incorporation of Cement Expanded Polystyrene for Use in Buildings

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Abstract: This work focuses on the development of local building materials in Benin for their efficient use in buildings. It aims to make mud bricks lightened with good mechanical, thermal and sound properties and enhance the waste polystyrene. This article is the result of experimental work on a broad field of applied sciences: building mechanics. The study is focused on BTS (blocks of stabilized earth) chosen as reference materials to which we linked polystyrene. The percentage of polystyrene varies from 0% to 100% starting from a constant volume of each reference material. The results showed that the increase in polystyrene percentage lowers mechanical properties. These results also showed that the gradual addition of polystyrene to the laterite-cement mixture has a significant influence on the density and mechanical resistances of the final composite material.

Key words: Characterization, bocks of compressed earth, polystyrene, mechanical resistances.

Nomenclature

B	Width (m)
E	Thickness (m)
F_f	Breaking load bending (N)
F_c	Breaking load compressive (N)
L	Length (m)
M	Weight (kg)
R_f	Flexural strength (MPa)
R_c	Compressive strength (MPa)
S	Area (m^2)
V	Volume (m^3)
P	Density (kg·m^3)
BTS	Stabilized earth blocks

1. Introduction

To partially address concerns, such as reducing electricity consumption in buildings, reducing the emission of gases through the greenhouse effect due to large air conditioning facilities and extra protection environment by recycling polystyrene waste [1-3], we conducted an experimental study on the behavior of BTS with added polystyrene. This is a study conducted in the LEMA (Laboratory of Applied Mechanics and Energetics), on the thermomechanical properties of BTS alleviated. According to our surveys, the addition of polystyrene in mortars and concrete help to achieve good thermal insulation of the envelope [4-6]. The main objective of this study is to experimentally characterize the mechanical behavior of BTS. One of the objectives is to find earth blocks acceptable mechanical properties to erect walls or fences and buildings that will be easy to implement as stipulated by the French and Belgian standards [7]. A weight ratio of laterite-cement constant equal to 9 was adopted for all compositions. Then, the main concern was to adjust to the amount of introduced polystyrene. Some preliminary tests have indeed shown that the workability of the mortar and the density of the blocks are affected by the introduction of polystyrene. The influence of the percentage of polystyrene on the bulk density has also been shown in this study, on the compressive strength of the cubic form of test

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specimens and the tensile strength of the samples.

2. Sample Preparation

2.1 Used Materials

All materials used in this work are of local origin. For making blocks, the used materials are: Cement CPJ 35, laterite or earth Bakhita bar, water and polystyrene. The latter component is also the only variable parameter.

2.1.1 Laterite or Earth Bar

Laterite used for making the blocks is a soil taken from Bakhita in Abomey Calavi, in the suburb of Cotonou in the Republic of Bénin. After drying the ground, it was sieved with two sieves (2 mm) for making test pieces to be cooked, taking into account the finer particle size clay. Fig. 1 shows the appearance of the used size.

2.1.2 Cement

The cement used for making blocks is CPJ-35 kind from the League of SCB Lafarge (Lafarge Cement of Benin). Fig. 2 shows the package of cement used for making cement blocks stabilized.

2.1.3 Polystyrene

The used expanded polystyrene beads are suitable for incorporation into the blocks. They have varying diameters. Its bulk density is about 17.5 kg/m^3, which is at least 60 times smaller than the densities of the clay and the earth bar. Fig. 3 shows photos of PES (polystyrene) waste and obtained ground product.

In this study, three granular classes were determined. Fig. 4 shows the appearances of the different classes. Only the granular class whose ball diameters are less than or equal to 2 mm was used.

Diameter $\Phi < 5$ mm

Fig. 1 Different sizes of used laterite.

Fig. 2 Photo of the used cement.

(a) (b)

Fig. 3 Photos of the used polystyrene: (a) PES waste; (b) ground product.

(a) (b) (c)

Fig. 4 Different granular classes PES: (a) $\Phi \leq 2$ mm; (b) $2 < \Phi \leq 4$ mm; (c) $\Phi > 4$ mm.

(a) (b) (c) (d)

Fig. 5 Photos of some used materials: (a) Mold 4 × 4 × 16; (b) Mold 10 × 10 × 3; (c) graduated container; (d) balance.

2.1.4 Dampening Water

Dampening water is distributed by the drinking water supply network of the University Campus of Abomey.

2.1.5 Materials

For making blocks, many current materials and supplies (scales, containers, trowels, molds, formwork oil, etc.) are used. Fig. 5 shows the pictures of some used materials.

2.2 Procedures

All samples were prepared manually; The mortar mixture is made using a trowel, and the blocks were molded by hand (hand molding). Standard prismatic tests French standard (NF P 18-400, NA 2600) of dimensions 4 cm × 4 cm × 16 cm have been used for the determination of flexural strengths three points. These same samples were used to determine the weight loss. Equivalent cubic specimens (4 cm × 4 cm × 16 cm) were obtained by crushing the resulting equivalent cubic test half-prisms.

The samples were first a course of 28 days, that is to say, they are protected from the sun and wind in a high relative humidity for 28 days to allow the cement to reach its maximum strength [8]. After curing, the blocks were always dried out of direct sunlight (avoid too rapid withdrawal) to allow evaporation of water and the removal of the clay fraction.

All tests were made with a temperature in an oven of 105 °C. For each type of test, the number of specimens is 3 and test body is 4 cm × 4 cm × 16 cm for mechanical testing and measurements of bulk densities.

For mechanical testing, testing in three flexure dots and those in compression on the half blocks from the flexural strength were performed.

2.3 Formulation

2.3.1 Dosage

The following percentages were studied:

- polystyrene: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the soil volume measured in accordance with the dosages adopted by Chafi [5] to properly highlight the influence of this by-product in low dosages;
- cement: 10% and 90% laterite.

Of course, for each characteristic of interest, the results were compared with a reference block (control) performed according to the same methods of implementation and earth assays, cement and water.

The only parameter changing from one to the other is

Table 1 Notations adopted for the different samples.

No.	Designation	Rating
1	Control block	F
2	Block reinforced with 10% polystyrene	F1
3	Block reinforced with 20% polystyrene	F2
4	Block reinforced with 30% polystyrene	F3
5	Block reinforced with 40% polystyrene	F4
6	Block reinforced with 50% polystyrene	F5
7	Block reinforced with 60% polystyrene	F6
8	Block reinforced with 70% polystyrene	F7
9	Block reinforced with 80% polystyrene	F8
10	Block reinforced with 90% polystyrene	F9
11	Block reinforced with 100% polystyrene	F10

mixed assay (content) of the PES.

The studied characteristics are as follows:

- density;
- the compressive strength and tensile strength by bending.

The notation F denotes blocks stabilized cement followed by a number which represents the percentage by volume of polystyrene added to 10.

Tables 1 and 2 show the values of different strengths for the manufacture of each type of sample.

2.3.2 Weight Loss Test

The withdrawal measures were accompanied by the weighing of 4 × 4 × 16 samples in order to determine their densities.

Measurements of weight variation were performed using an electromechanical balance to an accuracy of 0.1 g (Fig. 5).

2.3.3. Bending Tensile

The flexural tensile strength was determined using a three-point 10 kN bending machine and one 4 × 4 × 16 cm prismatic test in according with French standard NF P18-407 (NA 428).

The specimens were placed in the testing machines, as shown in Fig. 6.

After a perfect centering, the loading was the carried out with a constant speed of scalability. The machine is provided with a bending device is shown schematically whose principle in Fig. 7.

Denoting by F_f the failure of the test of load in bending, the moment of rupture is F_f × l/4 and the corresponding flexural stress was determined by:

$$R_f = \frac{1.5F_f l}{b^3} \tag{1}$$

2.4 Compression Test

The compression test is to break the test specimen between the two plates of a compression press. The press used is a compression machine with a capacity of 150 kN. The compression test on equivalent cubes 4 × 4 × 4 cm was made on the same compression machine. The half-prisms 4 × 4 × 16 specimens obtained after flexural strength were broken in compression, as shown in Fig. 8.

By appointing the breaking load of the compression cylinder F_c, the stress fracture at the corresponding compression was calculated by:

$$R_c(\text{MPa}) = \frac{F_c(\text{N})}{b^2(\text{mm}^2)} \tag{2}$$

Expressing F_c(N) and considering the section specimens (40 mm × 40 mm), this resistance (MPa) is:

$$R_c(\text{MPa}) = \frac{F_c(\text{N})}{1,600} \tag{3}$$

Following the withdrawal of the clay after firing, the compression breaking stress, for cooked blocks, is calculated by the following formula:

$$R_c(\text{MPa}) = \frac{F_c}{4b} \tag{4}$$

Table 2 Composition adopted for lightened with polystyrene block.

Items	Results										
Mixture volume (mL)	2,000										
Mixture content	Latérite/cement: 90%/10%										
Water (mL)	375										
PSE volume (mL)	0	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000
Corresponding PES weight (g)	0	3.5	7	10.5	14	17.5	21	24.5	28	31.5	35
Designation	F	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10

Fig. 6 The used bending machine.

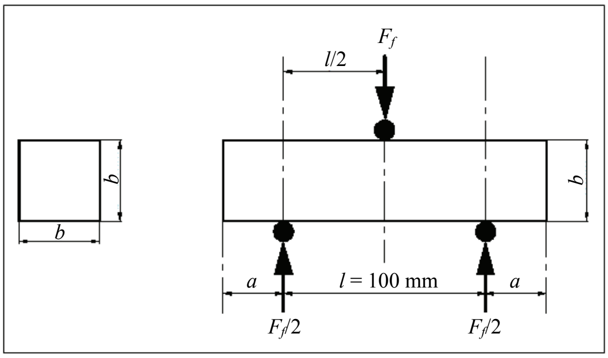

Fig. 7 Device tensile failure in bending.

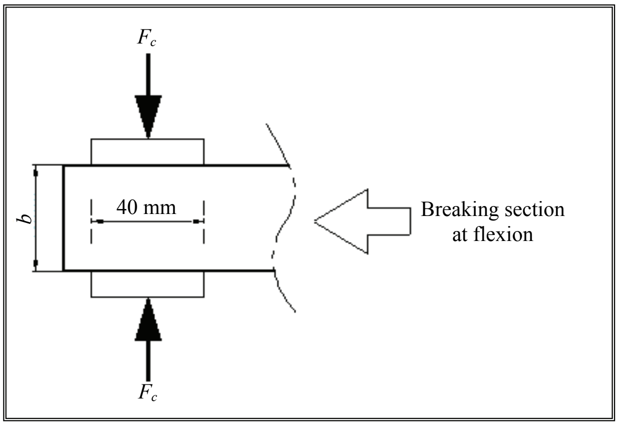

Fig. 8 Compression breaking device.

The results for each of the six half-prisms are rounded to 0.1 MPa, and then their average is calculated. If any of the results differs from 6 ± 10% of this average, it is discarded and the average is recalculated from the remaining five results. If again one of the five results deviates ±10% of this new medium, the series of six measures are dismissed as prescribed by the standard.

When the result is satisfactory, the obtained average is thus the resistance of the mortar to the considered age.

3. Results and Discussions

This section presents the different results obtained in this study and it aims to show the influence of the percentage of PSE on the bulk density, the compressive strength on cubic specimens and sample tensile strength.

3.1 Bulk Density ρ

The influence of the incorporation of the polystyrene beads on the density of the blocks was studied. All results obtained are summarized in Table 3. It is clear in Fig. 9 that the density of BTS eased decreases with increase in the percentage of PSE. For example, the density of the fired brick reference (F) is 1,896 kg/m^3, whereas the reinforced brick 100% PES (F10) is only 1,316 kg/m^3, which corresponds to a decrease of 31%. Ultra lightweight polystyrene aggregate is regarded as voids created within blocks explains this reduction in density.

The lightweight materials become very beneficial when the density reduction rate is at least equal to 15%. With stabilized earth blocks and lightweight, discounts up to 31% were obtained.

3.2 Influence of the PES on the Mechanical Performance

One of the important points to be considered in this

Table 3 Density polystyrene block of samples.

Designation	F	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
ρ (kg/m^3)	1,896	1,785	1,639	1,595	1,576	1,525	1,492	1,391	1,347	1,331	1,316
ρ/ρ_F (%)	100	94	86	84	83	80	79	73	70	70	69
Reduction (%)	0	6	14	16	17	20	21	27	30	30	31

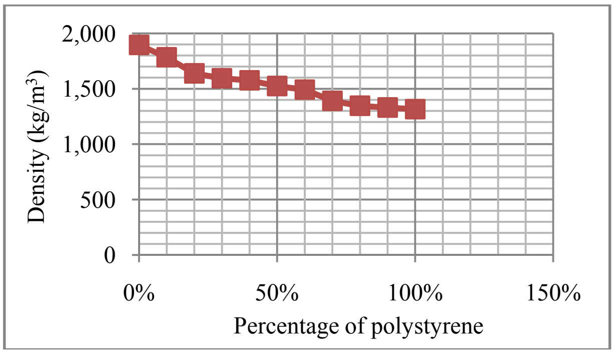

Fig. 9 Density of the tested samples.

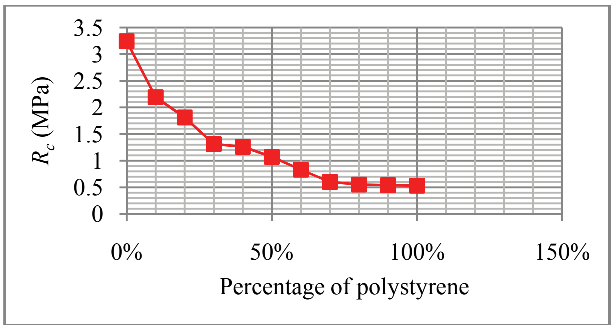

Fig. 10 Evolution of the compressive strength versus percent polystyrene beads.

research is indeed the mechanical performance. The strengthened polystyrene blocks were compared to control blocks to determine their influences depending on the dosages:

- cylinders prismatic 4 cm × 4 cm × 16 cm: for the testing of resistance to the three-point bending;
- half specimens broken in two parts during the bending test without changing the mechanical characteristics: for testing the resistance to compression.

The results of the companion measures are presented in the following.

3.3 Compressive Strength

The influence of the incorporation of the polystyrene beads on the resistance R_c of the compression blocks was studied. The obtained results are summarized in the Table 4 and represented by the curve.

Fig. 10 shows the development of resistance to compression of the blocks based on polystyrene rate.

In Fig. 10, a lower mechanical strength of the polystyrene blocks was observed, compared to control blocks when the polystyrene content increases. At contents ranging from 10% to 100%, the compressive strength is reduced from 6% to 68% relative to the control. These decreases on mechanical strength were observed by several authors (Chafi [5], Collins and Ravindrarajah [9]). Indeed, polystyrene aggregates create areas of weakness within the blocks and reduce the area of the resistant section of the test pieces.

3.4 Flexural Tensile Strength

All obtained results are summarized in Table 5.

The curve in Fig. 11 shows and confirms that the addition of polystyrene causes a reduction of the resistance of the blocks.

Whether three-point bending or compression occurs, the trend is the same: “The mechanical performance blocks with addition of PSE decrease with the content of PES”.

The appearance of the bottom curve (cold) is due to the progression of the values given by the measuring machine. Indeed, values change 100 N into 100 N; Therefore, all values, between 0 and 100 and between 100 N and 200 N, respectively, are rounded to 100 N and 200 N. It is this fact which explains the shape of the curve obtained due to low resistance of the blocks.

Comparing Figs. 10 and 11, it is noted that the bending strength is less sensitive to the polystyrene content than the compressive strength. Chafi [5] obtained similar results on polystyrene reinforced mortar. To explain this difference in behavior between the influence of polystyrene on the strength of the mortar

Table 4 Results of the compressive strength on samples cut 4 × 4 × 4 cm

Designation	F	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
R_c (MPa)	3.24	2.19	1.81	1.31	1.26	1.07	0.83	0.60	0.55	0.54	0.53
Reduction (%)	0	32	44	60	61	67	74	81	83	83	84

Table 5 Results of the bending strength on prismatic specimens 4 × 4 × 16 cm.

Designation	F	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
R_c (MPa)	3.24	2.19	1.81	1.31	1.26	1.07	0.83	0.60	0.55	0.54	0.53
Reduction(%)	0	32	44	60	61	67	74	81	83	83	84

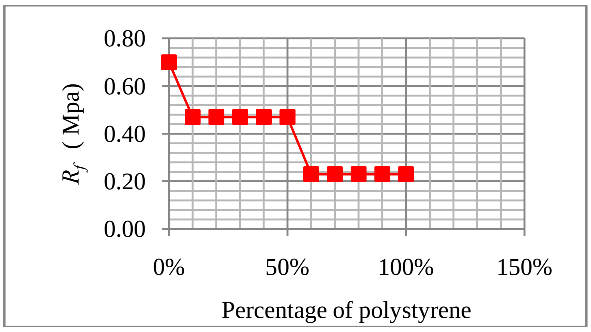

Fig. 11 Evolution of the flexural strength as a function of the percentage of polystyrene beads.

compressive and flexural strength, he is the link between the failure mode according to the mortar contains polystyrene or not; and found that the specimens containing polystyrene are not crushed into small particles, unlike those of the control. It has also made this observation during measurements. This means that there is a certain cohesion of the matrix due to adhesion between the cement paste and the beads. This same grip is useful to bending and helps keep higher proportions of resistance to bending in compression despite the presence of polystyrene.

4. Synthesis

The effects of the introduction of the polystyrene in the BTS are highlighted:

• A dropping resistor was expected since the polystyrene reduced resistant surface of a section. It is to manufacture blocks full of air pockets that have no resistance;

• Behaviors between compression and bending stresses are very different;

• By analogy with the resistance obtained during the compressive strength test, it is found that falls are identical to those of apparent densities, so there is a correlation between the two characteristics;

• The fall of the resistance to compression block is explained by the decrease in density due to charging of the internal structure of the latter.

5. Conclusions

The exploitation of experimental results has quantified most mechanical quantities and characteristics of developed samples. The experimental part of the study on the mechanical properties provides guidance for the choice of material for the thermal insulation of buildings, however, to consider other criteria for the final choice as behavior of these materials in contact with water. A first contribution concerns the development of new local composite materials for the building envelope.

After the experiment, the following conclusions were reached:

• The variation of these parameters is due to the nature of polystyrene dosing percentages in the composition;

• Depending on the percentage, increase in the polystyrene has been:

(1) a decrease in compressive strength;

(2) a decrease in the flexural resistance;

(3) a reduction in mass and density.

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