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Characterization of Cooked Bricks with Incorporation of Expanded Polystyrene for Use in Buildings

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ABSTRACT
This work deals with the valorization of local materials of construction in Benin in view of their efficient use in the buildings. Its objectives are to produce lightweight earthenware bricks with good mechanical and to upgrade polystyrene waste. It is the result of experimental work in a broad field of building mechanics. The study focuses on clay blocks selected as reference materials to which we have associated polystyrene. The percentage of incorporated polystyrene varies from 0 to 100% of the reference material volume. This volume constant and composed of 80% clay and 20% laterite. The results showed that the increase percentage in polystyrene lowers the mechanical properties (three-point flexion and compression). These results have also shown that the progressive addition of polystyrene to the clay-laterite mixture has a significant influence on the density of the final composite material.

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NOMENCLATURE

Denomination	Signification	Units
b	*Width*	*m*
e	*Thickness*	*m*
F_f	*Breakingload at bending*	*N*
F_c	*Compression breakingload*	*N*
L	*Length*	*m*
m	*Mass*	*kg*
R_f	*Bending Resistance*	*MPa*
R_c	*Compression Resistance*	*MPa*
S	*Surface*	m^2
V	*Volume*	m^3

Introduction

The building sector (residential and commercial) now accounts for just over one-third of the world's final energy consumption. In all developing countries, the share of its consumption exceeds 40%. According to the reference scenario of the International Energy Agency, the final energy consumption of buildings in the world could reach about 3800 million tons of oil equivalent in 2030, of which about half (1800 Mtoe) would come from developing countries. The building sector contributes significantly to climate change, with greenhouse gas (GHG) emissions accounting for about 20% of emissions from final energy consumption (excluding electricity). These emissions could rise to nearly 4,300 million tons of CO2 equivalent by 2030, more than half of which would be generated by developing countries. The building sector is therefore a crucial issue in terms of adapting to climate change because it is at the heart of a double problematic energy and environmental. To address some of the concerns, such as: reducing electricity consumption in buildings, reducing greenhouse gas emissions from large additional air conditioning systems and protecting the environment, (1), [2], [3], an experimental study was carried out on the behavior of baked bricks with the addition of polystyrene. This study is carried out in the Laboratory of Energetics and Applied Mechanics (LEMA), on the mechanical properties of cooked and lightened bricks. According to our surveys, the addition of polystyrene in mortars and concretes would contribute to good thermal insulation of the envelope [4], [5], and [7]. The main objective of this study is to characterize experimentally the mechanical behavior of cooked bricks. One of the objectives is to find land blocks of acceptable mechanical characteristics to erect walls or barriers of buildings and which will be easy to implement as stipulated by the French and Belgian standards [9]. A constant ratio of clay / laterite weight equal to 4 was adopted for all the compositions. Then it was to play on the amount of polystyrene introduced. A few preliminary tests have shown that the ability of mortar to be open, shrinkage, density of blocks, cracks in clay during drying and cooking are influenced by the introduction of polystyrene. The influence of polystyrene percentage on apparent density, compressive strength on the cubic specimens and tensile strength of the samples were also shown in this study.

Experimental

Materials used

All the materials used in this work are of local origin except the polystyrene. For the making of the blocks, the materials used are: Porto-Novo clay (latitude: 6°29'49'' North; Longitude: 2°36'18''East; elevation above sea level: 20m), Bakhita bar laterite or land (latitude: 6°26'54'' North; Longitude: 2°21'20''East; elevation above sea level: 11m), water and polystyrene, the latter component (polystyrene) being the only variable parameter.

Laterite or bar land

The laterite used for the making of the blocks is a ground taken from Bakhita in the region of Calavi. After drying the

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soil, it was sieved with two (02) mm sieves to prepare the test specimens in view of the finer particle size of the clay. The photo of figure 1 shows the aspect of the granulometry used.

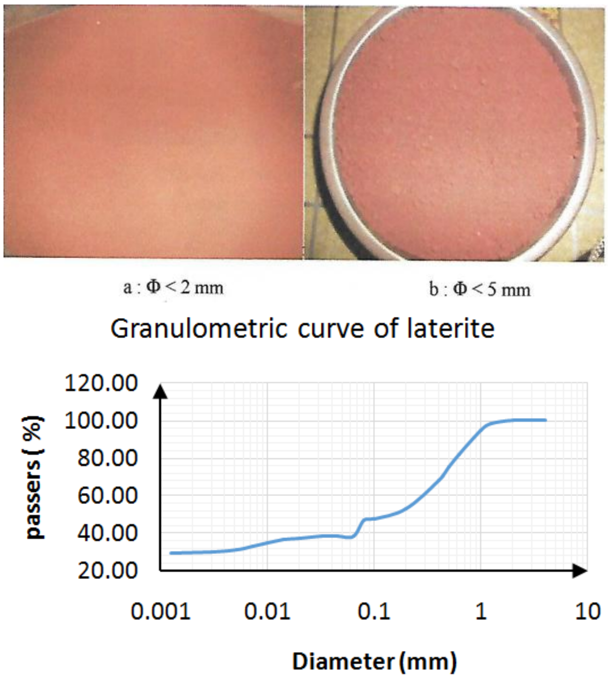

Figure 1 : Different granulometry of used laterite and granulometric curve

Clay

The clay used to make the blocks stabilized by firing is a gray clay from Porto-Novo. Its average bulk density measured in the dry state is 1200 $kg.m^{-3}$ [8]. Figure 2 shows photos of the clay used in the raw state and after sieving. Before usage, the clay was removed, dried, crushed and screened with a 2 mm sieve.

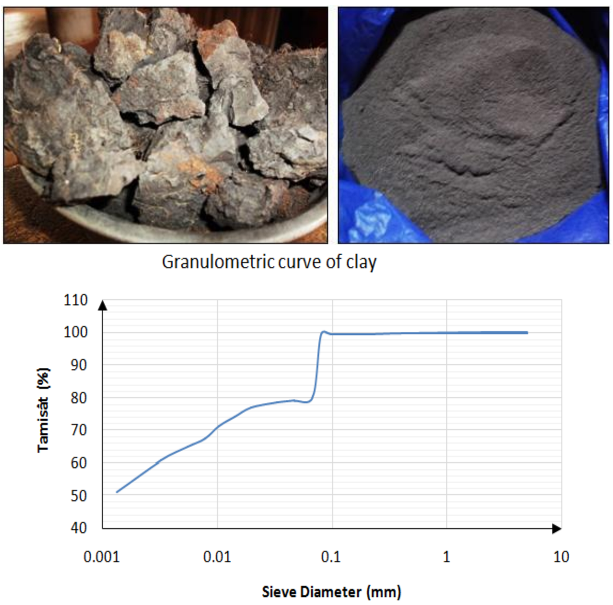

Figure 2: Photos of clay used and granulometric curve

Polystyrene

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

Figure 3 : Photos of used polystyrene

In this study, three granular classes were determined. Photos 1, 2 and 3 of figure 4 show the appearance of the different classes (see below). Only the granular class with ball diameters less than or equal to 2 mm was used (photo 1).

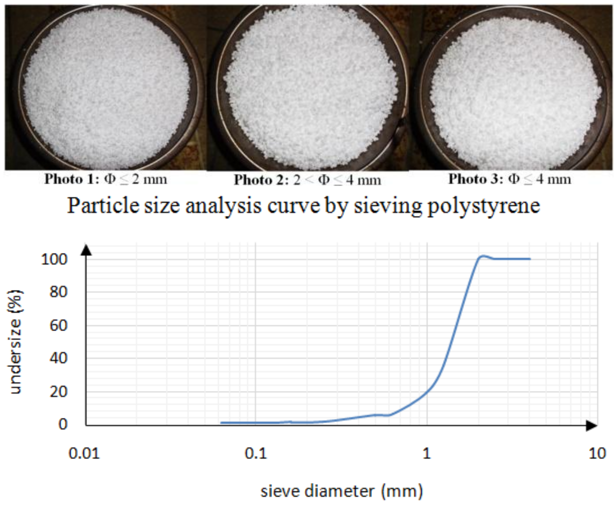

Figure 4 : Different granular classes of the PSE and granulometric curve

Wetting water

The moistening water (pH: 5.9; Temperature: 29.3°C, salinity: 0.26 mg/L; hardness: 351mg/L and electricity conductivity: 544µS/cm)is the one distributed by the drinking water supply network of the Abomey-Calavi University.

Several common materials and supplies (scales, containers, trowels, molds, formwork oil, etc.) are used to make the blocks. Figure 5 illustrates the photographs of some of the instruments used.

Figure 5: Picture of some of instruments used. (a) mold 4x4x16 cm, (b) mold 10x10X3 cm, (c) graduated container, (d) Balance

Procedure

All samples were developed manually; the mortar mixture is made using a trowel and the blocks have been molded with the hand (hand molding). The standard prismatic specimens (NFP 18-400, NA2600) of dimensions 4 × 4 × 16 cm were used for the determination of the three-point bending strengths (resistance). These same test pieces were used for the determination of the weight loss. The equivalent cubic specimens (4x4x8 cm) were obtained by crushing the equivalent cubes resulting from the half-prisms of the tests To avoid cracking and shrinkage problems, the samples were dried out of the sun, thus in the ambient environment of the laboratory (Temperature =28°C, Relative Humidity RH=78%).

All cooking, from preheating to cooling, lasts about 48 hours [10]; the product remains at maximum for ten hours in full fire. The cooking kinetics adopted corresponds to the cooking curve of Fig. 6.

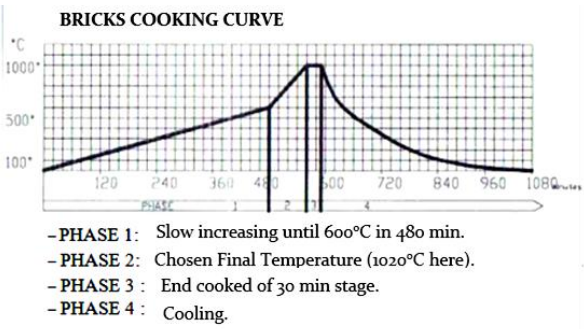

Figure 6: Curve showing the different phases of cooking [10]

All tests were carried out with an oven temperature of 105 ° C, and a firing temperature of about 1000 ° C. For each type of test, the number of test tube is three (03) and test bodies: 4x4x16 cm for mechanical tests and bulk density measurements. For the mechanical tests, the three-point bending tests and the compression tests on the half-blocks resulting from the bending failure were carried out.

Formulation

Dosage

The following percentages were studied:

• Polystyrene: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the volume of soil measured according to the dosages adopted by Shafi[5] (100% of the reference volume defined above corresponds to the volume of polystyrene equal to the volume of the reference material); In order to highlight the influence of this by-product in low dosages.

• Clay: 80% and laterite 20%. Of course, for each characteristic studied, the results were compared with a reference block (control) realized according to the same methods of implementation and dosages in earth and water.

The only parameter that changes from one mixture to another is the dosage (content) of the PSE.

The characteristics studied are as follows:

• The density;

• Resistance to compression and flexural tensile strength;

The notation C designates the blocks stabilized by firing followed by a number which represents the percentage by volume of polystyrene introduced on 10 (Table 1). Table 2 shows the values of the different assays for the preparation of each type of sample.

Table 1: Ratings adopted for the different samples

Designation	Notation
1/control block with 0% of polystyrene	C0
2/ reinforced block of 10% of polystyrene	C1
3/ reinforced block of 20% of polystyrene	C2
4/ reinforced block of 30% of polystyrene	C3
5/ reinforced block of 40% of polystyrene	C4
6/ reinforced block of 50% of polystyrene	C5
7/ reinforced block of 60% of polystyrene	C6
8/ reinforced block of 70% of polystyrene	C7
9/ reinforced block of 80% of polystyrene	C8
10/ reinforced block of 90% of polystyrene	C9
11/ reinforced block of 100% of polystyrene	C10

Table 2: Compositions of light weight blocks with polystyrene beads

Mixture (ml) Clay (80%)- laterite (20%)	2000										
Water (ml)	750										
Volume of PSE (ml)	0	200	400	600	800	1000	1200	1400	1600	1800	2000
Mass of corresponding PSE (g)	0	3.5	7	10.5	14	17.5	21	24.5	28	31.5	35
Designation	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10

Weight loss test

The removal measurements were accompanied by the weighing of the 4x4x16 test pieces in order to determine their densities. The weight variation measurements were carried out using an electromechanical balance allowing an accuracy of 0.1 gram (Fig. 5d)

Bending

The flexural tensile strength was determined using a 3-point 10 kN bending machine on 4x4x16 cm prismatic specimens in accordance with NF P18-407 (NA 428). The specimens were placed in the test machine as shown in figure 7. After perfect centering, loading was carried out at a constant load rise speed. The machine is provided with a bending device, the principle of which is shown schematically in Fig. 7.

Figure 7: Machine for bending test

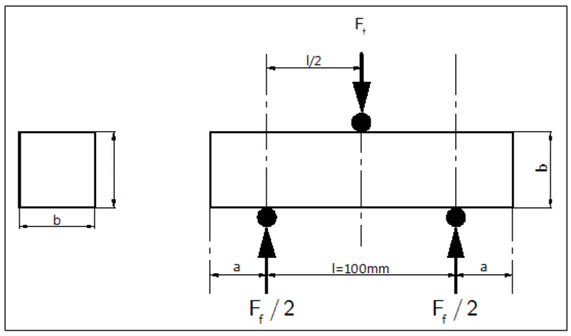

Figure 8 : Device of rupture in traction by bending

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If F is the breaking load of the specimen in flexion, the moment of rupture is Ff × 1/4 and the corresponding bending stress has been determined by:

$$R_f = \frac{1{,}5F_f l}{b^3} \quad (1)$$

Compression test

The compression test involves breaking the test body between the two platens of a compression press. The press used is a compression machine with a maximum capacity of 150 kN. The compression test on equivalent cubes of 4x4x8 cm was carried out on the same compression machine. The half-prisms of the 4 × 4 × 16 specimens obtained after bending fracture were broken in compression as indicated in Fig. 9.

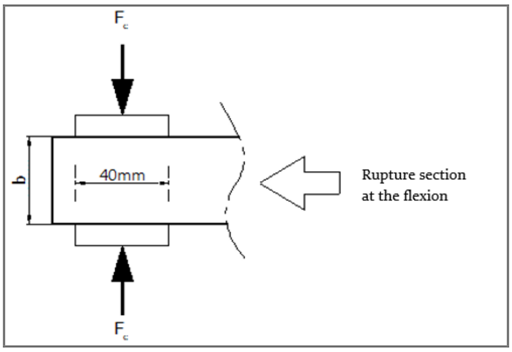

Figure 9*:* Device of rupture in compression

By designating Fc the breaking load of the test piece in compression, the corresponding compression failure stress was calculated by:

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

By expressing Fc in newton and considering the section of the test pieces (40 mm × 40 mm), this resistance in mega Pascal is worth:

$$R_c(MPa) = \frac{F_c(N)}{1600} \quad (3)$$

In view of the shrinkage of the clay after firing, the compressive rupture stress for the fired blocks is calculated by the following formula:

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

The results obtained for each of the 06 half-prisms are rounded to the nearest 0.1 MPa and then their mean is calculated. If one of the 06 results differs by ± 10% from this mean, it is discarded and the average is then recalculated from the remaining 5 results. If again one of the 05 results deviates by ± 10% from this new mean, the series of 06 measurements is discarded as foreseen by the standard. When the result is satisfactory, the average thus obtained is the resistance of the cooked brick at the age considered.

Results and Discussion

This part presents the different results obtained in this study in order to show the influence of the percentage of PSE on the bulk density, the compressive strength on the cubic-shaped specimens and the tensile strength of the samples.

The apparent density ρ

The influence of the incorporation of the polystyrene beads on the density of the blocks was studied. The results obtained are grouped together in Table 3 and represented by the curve of Fig. 10.

Table 3: Density of polystyrene block samples

Designation	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
ρ (kg/m³)	1750	1706	1642	1586	1527	1479	1344	1342	1337	1254	1199
ρ/ρc(%)	100	97	94	91	87	85	77	77	76	72	69
Reduction(%)	0	3	6	9	13	15	23	23	24	28	31

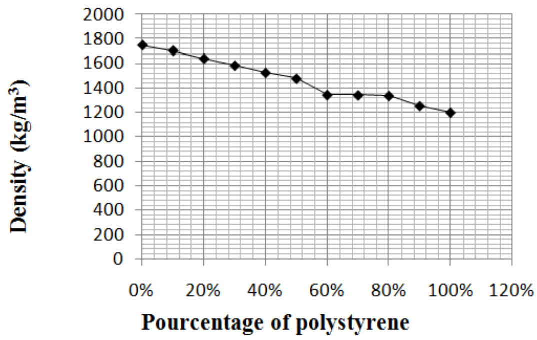

Figure 10: Tested samples density

It is clear from figure10 that the density of the cooked light bricks decreases with the percentage increase in PSE. For proof, the density of the baked reference brick (C0) is 1750 kg.m^{-3}, whereas that of the brick reinforced with 100% PES (C10) is only 1199 kg.m^{-3}, corresponding to a decrease of 31%. The ultra-light weight of the polystyrene aggregates, which can be considered as voids created inside the blocks, explains this reduction in density. The lightened materials become very beneficial when the rate of reduction of the density is at least equal to 15%. With stabilized and lightened earth blocks, reductions of up to 31% have been achieved and it is possible to go even further.

- The influence of PSE on mechanical performance: One of the important points to study in this research is indeed mechanical performance. The polystyrene reinforced blocks were compared to the control blocks in order to determine their influences as a function of the assays. The tests were carried out on: Prismatic test specimens 4x4x16 cm: for testing the three-point bending strength.
- Half-specimens broken in two parts during the bending test without modifying their mechanical characteristics NF EN [11]: intended for testing the compressive strength.

Compressive strength (resistance)

The influence of the incorporation of the polystyrene beads on the compressive strength Rc of the blocks was studied. The results obtained are grouped together in Table 4 and represented by the curve of Fig. 11. The results of the companion of measurements are presented in the Table 4.

Table 4: Results of the compressive strength on cubic specimens 4 × 4 × 8 cm

Designation	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Rc (MPa)	9.51	8.95	8.04	5.71	5.2	4.8	3.44	3.26	3.25	3.17	3.08
Reduction (%)	0	6	15	40	45	50	64	66	66	67	68

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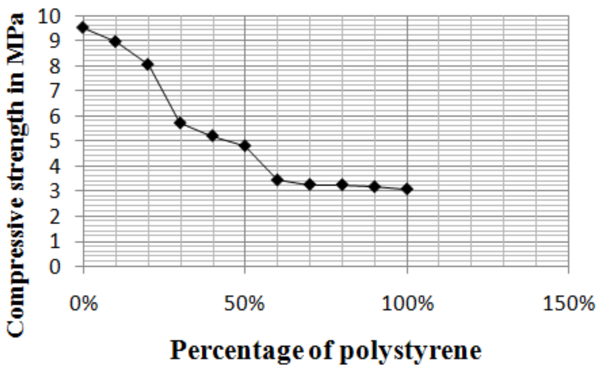

Figure 11: Evolution of the compressive strength as a function of the percentage of polystyrene beads

In the above figure, there is a decrease in the mechanical strength of the polystyrene blocks compared to the control blocks, as the polystyrene content increases. At contents ranging from 10 to 100%, the compressive strength is reduced by 6 to 68% relative to the control. These decreases in mechanical resistance have been observed by several authors including Chafi [5], Collins & Ravindrarajah [6]. Indeed, the polystyrene aggregates create zones of weakness inside the blocks and reduce the area of the resistant cross-section of the specimens.

Tensile strength by bending

All the results obtained are summarized in Table 5.

Table 5: Results of the flexural strength on prismatic specimens 4 × 4 × 16 cm (hot)

Designation	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Rc (MPa)	1.22	1.16	0.80	0.50	0.69	0.59	0.50	0.47	0.45	0.36	0.32
Reduction (%)	0	5	34	59	43	57	59	61	63	70	74

The curve in the figure below (figure 12) shows and confirms that the addition of polystyrene gives rise to a decrease in the resistance of the blocks.

Whether in three-point flexion or in compression, the trend is the same: "the mechanical performance of the blocks with the addition of PSE decreases with the PSE content". By comparing Fig. 11 and Fig 12, it is noted that the compressive strength is less sensitive to the polystyrene content than the flexural strength.

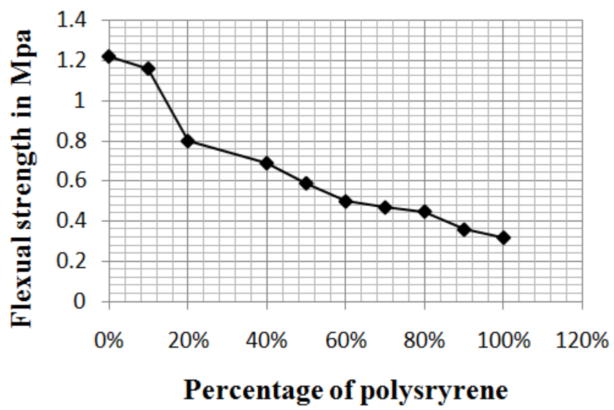

Figure 12: Evolution of the flexural strength as a function of the percentage of polystyrene beads

The polystyrene consumed during cooking improves the quality of the cooking (FIG. 13), but the voids left on the inside and sometimes on the surface are not very favorable to bending. Improving cooking is useful for compression.

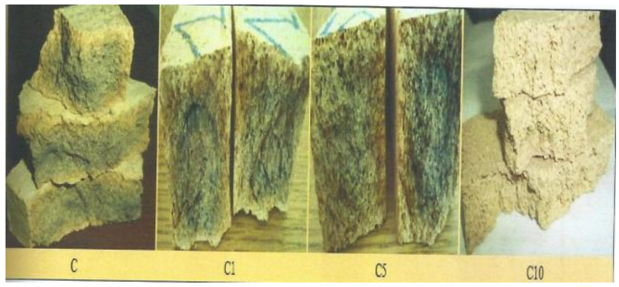

Figure 13: Quality of cooking according to percentage of polystyrene beads

Synthesis

The effects of introducing polystyrene into BTS are highlighted.

- A drop in strength was predictable, because polystyrene reduces the toughness of a section. It consists in making blocks full of pockets of air which have no resistance;
- A very different behavior between compression and bending stresses;
- By making an analogy with the resistances obtained during the tests of resistance to compression, it is found that the drops are identical to those of the apparent densities, so there is a correlation between the two characteristics;
- The fall in the compressive strength of the block is explained by the decrease in its density due to the loading of the internal structure of the latter.

The results above have also been validated by the work of AGAGBE [12].

Conclusions

Using the experimental results obtained, it was possible to quantify most of the mechanical quantities, characteristic of the samples produced. This experimental part of this study, which deals with mechanical properties, gives indications for the choice of a material for building, but other criteria must be taken into account for the final choice, such as the behavior of these materials in contact with water. A first contribution concerns the development of new local composites for the building envelope. After the experiment, the following conclusions were drawn: the variation in these parameters is due to the nature of the percentages of polystyrene in the composition.
Depending on the increase in the percentage of polystyrene there were:

1. A reduction in compressive strength;
2. Reduced flexural strength;
3. A decrease in mass and density.

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