Physical Science International Journal
12(4): 1-9, 2016; Article no.PSIJ.29393
ISSN: 2348-0130

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Thermomechanical Characterisation of Compressed Earth Blocks Added with Sawdust

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Authors' contributions

This work was carried out in collaboration between all authors. Author CAT designed the study, wrote the protocol and wrote the first draft of the manuscript. Author GCS managed the literature searches and analyses of the study performed the spectroscopy analysis. Authors CA and SA managed the experimental process. Authors AV and GD identified the local building materials. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/PSIJ/2016/29393
Editor(s):
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Complete Peer review History: http://www.sciencedomain.org/review-history/17087

Original Research Article

Received 8th September 2016
Accepted 12th November 2016
Published 1st December 2016

ABSTRACT

The study of mechanical resistances twined to standards dispositions allows keeping a composition of CEB measured out 10% of cement and 2% of *Tectona grandis* sawdust. This composite material offers a higher strength compared to the one obtained with Afzelia sawdust. The method of asymmetric hot plan has been used to determine the thermal conductivity of the material and deduct the thermal parameter such as the diffusivity, the effusivity and calorific capacity. This method proceeds by a quadripolar modelisation 1D and allows to represent with a good precision the temperature in the center of a drill linked to the studied samples. The results that are obtained have shown that the addition of sawdust to the ordinary compressed earth blocks has clearly improved isolation performances of the final composite material.

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Keywords: Compressed earth block; sawdust; mechanical resistance; thermal parameters.

NOMENCLATURES

a	:	*Thermal diffusivity ($m^{-2}.S^{-1}$)*
BTC	:	*Compressed earth block (CEB)*
CEB 10	:	*CEB dosed at 10% cement*
CEB 8	:	*CEB dosed at 8% cement*
CEB 6	:	*CEB dosed at 6%*
Cp	:	*Calorific capacity $J.m^{-3}.K^{-1}$*
E	:	*Separatement between (cm)*
F	:	*Maximal charge supported by two half block (kN)*
V	:	*Volume (m^3)*
F'	:	*Resistance to tests compression, MN/m^2*
GTR	:	*Earthworks Road Guide*
H	:	*Thickness of the blocks (cm)*
L	:	*Width of the blocks (cm)*
M	:	*Mass of the material (kg)*
P	:	*Charge at the break (KN)*
S	:	*Average surface of tests face (cm^2)*
X	:	*Water content (kg water.$kgms^{-1}$)*

Greck Symbols

λ	*: Thermal conductivity ($W. m^{-1} .k^{-1}$)*
ρ	*: Volumic mass ($kg.m^{-3}$)*

Subscripts

a	*: Apparent*
b	*: Test*
e	*: Water*
ec	*: Sample*
h	*: Wet*
i	*: Initial*
Xop	*: Optimal water contents*
S	*: Dry*

1. INTRODUCTION

The recent researches on the local material have shown that the earth offers a great potentiality to the different need of human beings. Houben H. and Guillaud H. have precised that, this kind of material doesn't really get, at natural state that people wanted to grant it, the thermal performances [1]. Nethertheless, when the earth material was mixed to other materials, these external, like fibrous materials and the linking, participate to the improvement of its performances, as well mechanic as thermal one. So the sawdusts generally are raised to be suitable as adjuvant in earth composite materials [2-5]. In practice, wood processing companies in developing countries generate more than 30 to 50% of the waste treated wood volume, according to the case. These wastes are often used as a solid fuel, which promotes consequently the substantial production of carbon dioxide ($C0^2$): a greenhouse gas, which contributes to the destruction of the ozone layer [6].

In order to participate to the fight against the degradation of environment many researchers are interested on nowadays in the valorization of wastes, the recycling. It's in this context that this study has permitted to explore the possibilities of compressed earth blocks utilization with sawdust addition.

2. MATERIALS AND METHODS

2.1 Materials

Sample material which constitutes the basic element for out study is a laterite composite + cement + sawdust + water in good studied propositions.

2.1.1 The earth

The laterite used is from Woba Karou in N'dali district See Fig. 1 (area located in the Northern Benin in the department of Borgou). The Fig. 1 show the geographical location of the sampling site of laterite.

2.1.2 The cement

The cement portland CPJ 35 has been used for this study because of its relative quick adherence.

2.1.3 The sawdusts

The sawdusts of two species of tropical woods have been exploited. Afzelia and teck woods are concerned, recognized for their availability in Benin.

2.1.4 The stove and the scales

A ventilated stove of Memmert mark DO6060, functioning between the temperatures range (T) as 30℃ $\leq$ T $\leq$ 225℃ with a ventilation register, setting from 0 to 6, has permitted to dry the sawdust sample and to determine the dry extracts of compressed earth blocks (CEB). Two scales Sartorius type (precision 0.01 g) and

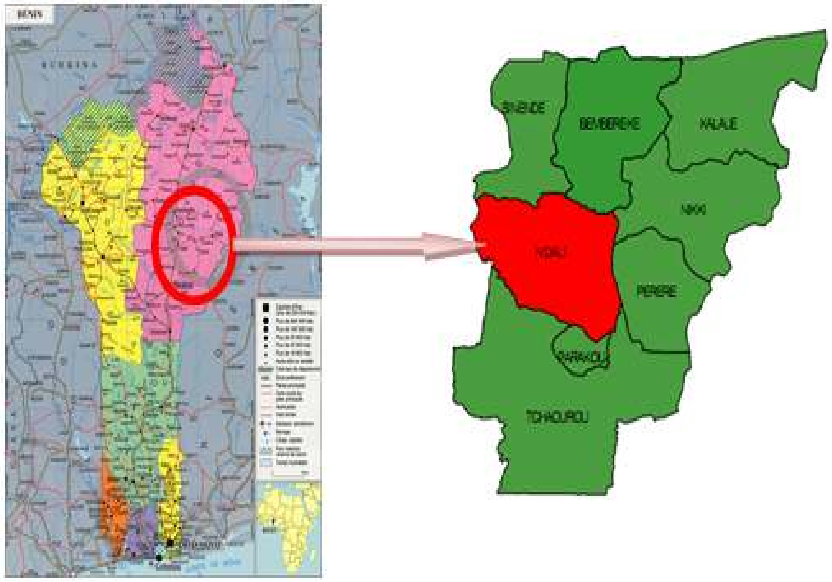

Fig. 1. Geographical location of the sampling site of laterite

Roverbal with a respective weight expanse of 3100 g and 20 000 g, have been used for the different internal weights forming the mixture. A belcher of 500 ml capacity has allowed to determine the volume of water constituting the block sample composition. The water that is used is the one supplied by National Society in charge of water in Benin.

2.1.5 Hydraulic press (squeezer)

It's a mechanic squeezer type SATEC MKIII-60 TVI, equipped with a command console digital hill porting. It has been used for resistance tests in flexion of three points and in compression.

2.2 Methods

2.2.1 Physical characterization of the laterite

In this part of the study, we have been interested on the characterization of the laterite of Woba Karou careers. This characterization consisted on the determination of physical properties like: the water content, the granulometry, the Atterberg limits, the volumic mass in bulk, the compressibility, the equivalent in sand and the real volumic mass of the produce ante-dried (Specific weight) [7,8]. Fig. 2 illustrates the particle size of the earth.

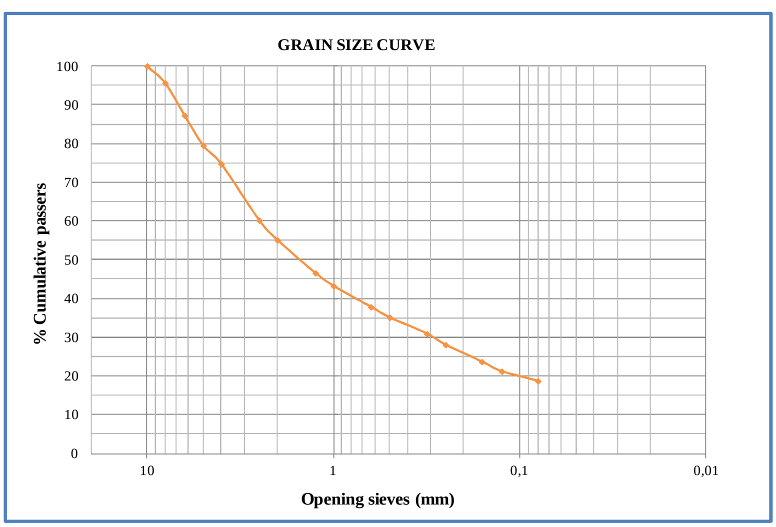

Fig. 2. Grading curve of the laterite

2.2.2 The cement

The cement portland CPJ35 used has been preserved in better conditions of temperature and humidity during 7 days in order to reach its maximal resistance to permit the relative quick use.

2.2.3 The sawdust

Sawdust samples treatment consisted on soaking in hot water previously brought at 105℃ during 48 h. The mixture obtained has been decanted and cooled down. The soaking water cooled down has been removed and replaced by the current water. The saw dusts have been neatly cleaned. The washing water has been filtered and replaced by current water in which the sawdust has been rinsed out. This approach permits on the one hand to dissolve in water inhibition extractible substances contained in the sawdust, and on the other hand to eliminate the microorganisms eventually present inside the sawdusts. The sawdusts neatly cleaned have been recuperated and piet inside the stove (oven) at 105℃ during 72 h.

Out of the oven, they has been spread on a tray and preserved in atmosphere conditions for 24 h to be adapted to atmosphere conditions. The sawdusts of each wood genus are examined closely and the fractions of sawdusts of granular class 0.16-5 mm have been packed and preserved far from humidity and heat under closed package until CEB realization.

2.2.4 Test realization (BTC)

- ✓ Cycle of compressed earth production

  A pre-treatment by sieving, with sieve of stitch of 10 mm laterite destined to the confection of EBC has been useful because of the presence of big particles in the earth samples, which have been spread in thin lagers at atmosphere temperature during 7 days in order to insure a natural drying. The water content of laterite has been determined X_{cc} in order to deduce the indispensable water volume to the composite mixture. In the same way, the masses of different components contributing to the preparation of dry mixture have been obtained. An adequate mixture of laterite + cement + sawdust + water has been realized and introduced into the press for the confection of CEB.

- ✓ Water volume of production

  Messing water has been progressively brought until the mortar is brought to the optimal content in water (Xop) of the earth determined for Proctor test. So the volume of water in liter to add has been given by the following formula:

$$V_e = \frac{\left(X_{op} - X_{ec}\right)M_1}{100 + X_{ec}} \qquad (1)\ [3]$$

Tests production CEB has been done according following the important steps: extraction, preparation, mixture, pressing, treatment and storing.

- ✓ Massic composition of CEB tests

  Table 1 informs on massic composition of different mixtures (laterite + cement + sawdust + water) realized for the sampling.

Table 1. Massic composition of CEB tests

	Laterite (Kg)	Sawdust (Kg)	Cement (Kg)	water (L)
CEB dosed at 4% of sawdust	7,74	0,36	0,9	0,5
CEB dosed at 6% of sawdust	7,56	0,54	0,9	0,5
CEB dosed at 8% of sawdust	7,38	0,72	0,9	0,5
CEB6	8,46	*	0,54	0,5
CEB8	8,28	*	0,72	0,5
CEB10	8,1	*	0,9	0,5
CEB dosed at 2% of sawdust	7,92	0,18	0,9	0,5

- ✓ Treatment and storage of blocks

  The local where the blocks are manufactured is well isolated from solar radiance and the treatment has been done under a transparent covering of polyster. This precaution has permitted after the 7th day of preservation to prolong the treatment opened in the local without damages on the blocks.

2.2.5 Mechanical characterization of CEB

In the context of this study, we have been interested in classical characteristics as below: the resistance in inflexion three points, in compression. For the test of resistance in flexion in three points, the block support face has been installed on two tubes spaced out of 20 cm and perpendicular to the block length, in the middle of the superior face, a third tube parallel to the firsts has been installed .We submit the CEB test to a constant charge at the rupture. The resistance to the blocks flexion has been determined by the formula:

$$\sigma = \frac{1.5 * E * P}{L * H^2} \quad (2)$$

Fig. 3. Test of resistance in inflexion (three points) on CEB

That is adopted the procedure for resistance in compression test has also permitted to take the twos halves of the test CEB stemming from flexion in three points tests. The two half – blocks were not always identical with regular forms. So the section held for the calculations is the mean average of the surfaces inferior and superior of the half-blocks. The resistance to the compression has been obtained by the formula:

$$F'_{sec} = 10 * \frac{F}{S} \quad (3)[9]$$

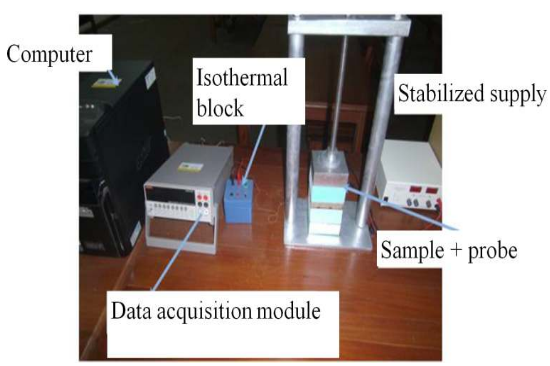

Fig. 4. Experimental mechanism of thermical characterization of experience test

2.2.6 Thermical characterization of CEB

The thermical properties assessed in the context of this work are: thermical conductivity, thermical diffusivity, the effusivity, calorific capacity. The method chosen here is the « asymetric hot plan » method materialized by the picture below. We have used a program of simulation on support « Matlab » for the estimation of thermical parameters.

3. RESULTS AND DISCUSSION

3.1 Mechanical Characteristics of CEB

The laterite water content sampled at Woba karou is estimated at 1.3%. Its granularity was inferior to 35% and the percentage of fines is about 17.23%.

The maximal diameter of grains is about 10mm (inferior to 50mm). Referring to the standards of classification NFP 11-300 and the GTR 92, we can deduce that the laterite used for our study belongs to class B (it has thus been sampled in sandy ground and grave lows one with fines) [10]. This assertion is confirmed by the theory about Atterberg limits in which the plasticity indice found is about 15.66% (superior to 12%), what allows to conclude with precision that laterite sample belongs to the under class B6. (Sand and clay grave to very clayer). Moreover, this type of laterite replies to Ramillon and Cratere granulometric standard, which recommends that fines percentage must be between 15 and 30% so as to be used for CEB manufacturing. According to the standards ARS 681: 1996 compressed earth blocks good manufacturing process in manufacturing of earth mortar, the earth of under –class B6 were acceptable for realization of CEB, Consequently, Woba Karou laterite can be used for CEB realization [4,11,12].

Proctor tests permit to emphasize on the following characteristics for the studied laterite: an optimal water contents (X_{op}) about 5,82% and a maximal dry density ($\gamma_{d\max}$) about 2,27 $T.m^{-3}$. Beyond these characteristics, we can notice that the consistence indice I_c > 1.3 So according to the standards NFP 11-300 and knocking down transport (KDT), the laterite used was at a very dry state; its equivalent in sand is Es=20%, this confers to this material a perfect stability and a sawdust textures [10]. Its use for the CEB is thus possible and can provide good results. The cement CPJ 35 from SCB Lafarge society has been used for the composition of the sampled mixture. It was produced according to the standard, NF P15-301 and allows a relatively rapid taking [13]. The third constituent of the mixture is the sawdust stemming from wood species: *Afzelia africana* and *Tectona grandis*.

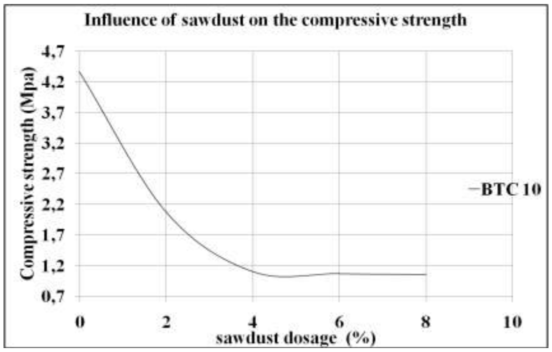

Fig. 5. Influence of dosage of Afzelia sawdust on the resistance in compression

The Figs. 5 and 6 present the influence of measuring out of Afzelia sawdust in the resistance in compression and inflexion in three points. Between 0 and 3% average, we notice a rapid decreasing of CEB resistance in which stabilizes at an average value about 1 Mpa for the resistance in compression and about 0.23 for the resistance in three points flexion.

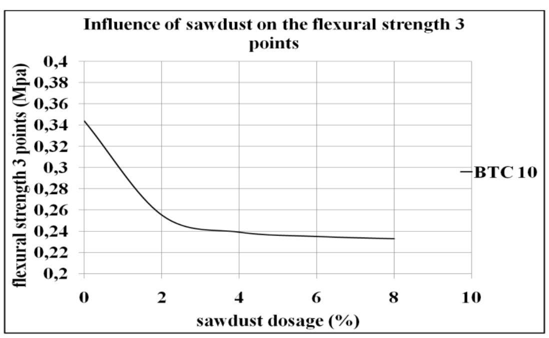

Fig. 6. Influence of dosage of Afzelia sawdust on the resistance in three points flexion

The mechanical performances of CEB with addition of sawdust are reversely proportional to the sawdust quantity inside the composite mixture the works of Solomon-Ayeh supported by the standards ARS 674:1996 and ARS 675:1996 indicate that a CEB material can be used in building when its resistance in compression is superior to 2MPa [6,9,14]. We will also retain that the content in cement has an influence on the mechanical resistances of CEB studied this influence has an increasing look and linear for the case of resistance in flexion, with a minimum in the coordinates points (6; 0, 27). As for the resistance in compression, it is proportional to the content in water, with a minimal value around 2.25 Mpa.

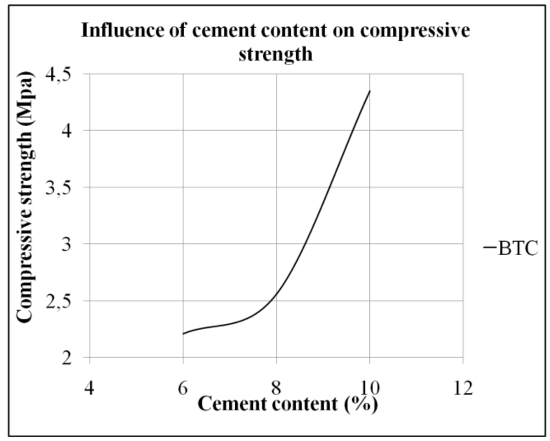

Fig. 7. Influence of cement content on the resistances in compression

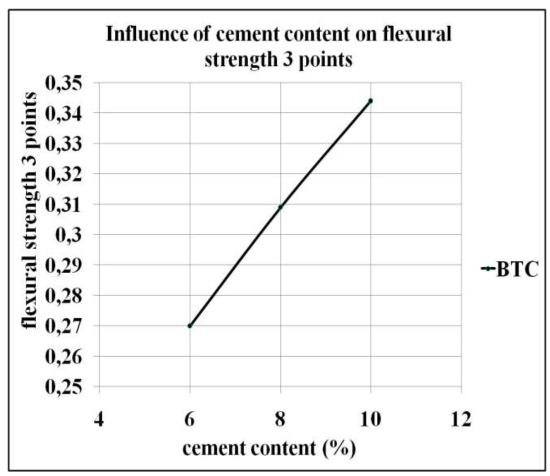

Fig. 8. Influence of cement content on the resistances in flexion three points

The curves of Figs. 7 and 8 show up to an addition of 10% of cement, the mechanical resistances of CEB rise in proportion with cement dosage. Consequently, the mixture sample of CEB studied has been dosed at 10% in cement. Peltier correlation (8) presented in the formula (3) expresses the optimal water content offering a maximal resistance for the test in flexion in three points. This expression has been retaken by Olodo and Rigassi who confirmed it has been applicable for the case that the CEB is without addition. For this study, the samples-test in CEB has been realized by compressed earth block (CEB) with addition of sawdust [15,16]. Assembling the sawdust to a granular material and making analogy between the two types of CEB with and without sawdust addition, we theorically deduce that the optimal water content of CEB with Afzelia sawdust has permitted to reach a water volume of wasting in level of Ve = 470 cl. The experimental curve of Fig. 9 presents a value Ve = 460 Cl, which corresponds to a maximal resistance in flexion three points. So, a relatively very weak interval of (2.12%) in touch with obtained values Ve has been noted; that permits to conclude that the correlation is well applicable for the studied CEB with sawdust addition

3.2 Mechanical Characteristics of CEB with Sawdust Addition

The graphs of Figs. 10 and 11 give a general idea of mechanical resistances of CEB with addition of sawdust coming from essences of *Tectona grandis* and Aflzelia africana.

The composites on the basis of *Tectona grandis* sawdust shows a resistance sensitively superior to those elaborated on the basis of *Afzelia africana* sawdust. The values of the resistance obtained for the two realized tests respect the requirements of Standards ARS674: 1996 and ARS 675: 1996.

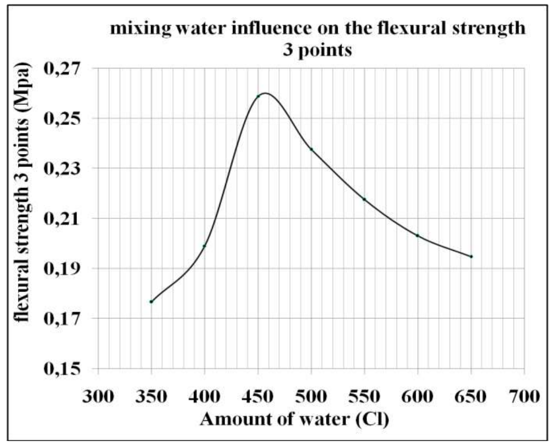

Fig. 9. Influence of wasting water on the resistance in flexion three points

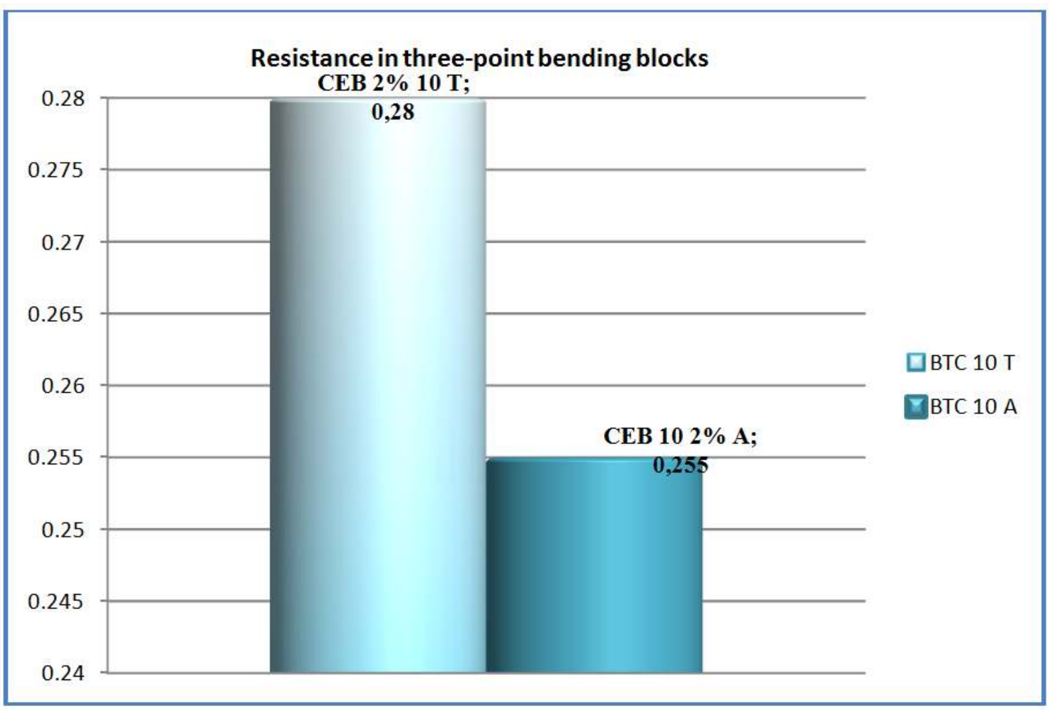

Fig. 10. Resistance in flexion three points and in compression with *Afzelia africana* and *Tectona grandis* sawdusts

Table 2. Thermal characteristics values evaluated for CEB 10 and CEB 10- T-2%

Parameters	Average values						
	Thermal effusivity	Uncertainty on thermal effusivity%	Thermal conductivity λ $w.m^{-1}.K^{-1}$	Uncertainty on thermal conductivity %	Thermal diffusivity $m^{-2}.S^{-1}.10^{-7}$	Calorific capacity J. $m^{-3}.K^{-1}$	Estimated times
CEBC 10	1811.00	0.45	1.70	1.10	8.91	1925759.79	350
Standard deviation	54.37		0.08		0.26	2932.49	
CEB 10-T-2%	1317.89	0.02	0.85	0.08	4.16	2042773.42	650
Standard deviation	1.83		0.01		0.09	22968.73	

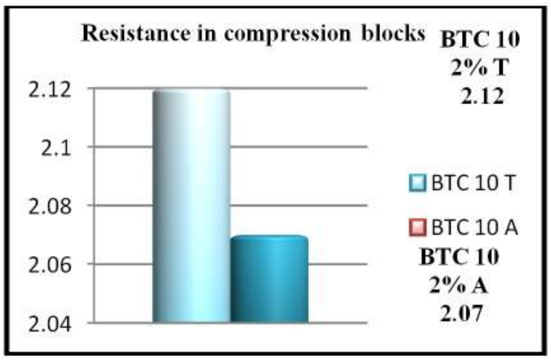

Fig. 11. Resistance in flexion three points and in compression with *Afzelia africana* and *Tectona grandis* sawdusts

3.3 Thermal Characteristics of CEB with or without Sawdust Addition

The results obtained for the CEB 10 at the end of thermal test are presented in the Fig. 10.

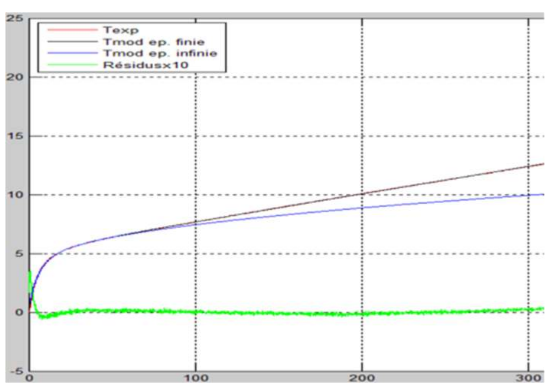

Fig. 12. Curve experimental model and testing of residues on the sample 10 BTC

The theoretical and experimental curves are superimposed perfectly and the residues are well equally flat. This confirms the accuracy of operations.

4. CONCLUSION

These reports enumerated above show CEB incorporating *Tectona grandis* sawdust constitute an isolant which could play a very interesting role in the field of energic efficience The values of thermal parameters wanted for BTC 10-7-2% and BTC-10 as following: calorific capacity, thermal diffusivity thermal effusivity and thermal conductivity are summarized in the Table 2. The blocks without sawdust addition present effusivity and thermal conductivity values superior to those of CEB with addition. This means that the conduction of heat by a material is intimately linked to thermal conductivity and to the effusivity. It stands out from this that CEB incorporating *Tectona grandis* sawdust conducts less heat. It's the same thing for the CEB with sawdust addition which diffuses less heat than classic CEB. Bisides, as the table 2 presents it at 2% of sawdust addition; CEB gets a better calorific capacity. Consequently our material, in addition to the fact that in limits heat conduction, it gets a strong capacity of storing.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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