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Development of a Composite Eco-Material Based on Typha from a Clay Matrix

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Abstract: This work focuses on the design of a new type of eco-material based on Typha "Domingensis" and clay from the south of the Republic of Benin through various dosages. Three particle size classes of typha shavings were selected to be mixed with two types of clayin order to make parallelepiped shaped samples ready for experimentation. The massive use of these briquettes thus obtained, in the construction of habitats, would not only contribute to reducing the energy consumption inside the dwellings but also would limit the invasion of the waterways of Benin, which would facilitate navigation, fishing and river sanitation activities. In addition, this biosourced, low-polluting material would contribute to improving the energy transition by integrating it into rehabilitation of buildings.

Key words: Typha "Domingensis" clay, eco-composite material, energy saving, environmental protection.

Nomenclature

M_e	mass of water added	(g)
M_m	total mass of the mixture	(g)
H_m	humidity of the desired mixture	(%)
M_T	total particle mass of typha stems	(g)
H_T	particle humidity of typha stems	(%)
M_A	mass of clay introduced	(g)
H_A	clay humidity	(%)
M_A	clay mass	(g)
M_T	total particle mass of typha stems	(g)

1. Introduction

In general, construction materials have a direct impact on the immediate environment of the human being. According to the results of recent studies, the construction sector is therefore responsible for 50% of the exploitation of natural resources, 45% of the total energy consumption, 40% of the waste produced and 16% of the consumption of water [1].

The general well-being of any individual therefore requires man to make an appropriate management of the resources made available to him for better protection of the environment without slowing down the economy [2-4]. Since then, researchers have invested in the development of new types of material of the composite type by introducing agricultural waste, plant stems, etc. into concrete and cement mortars to improve energy saving in the building. Thus energy efficiency in this sector is gradually being improved in the tropics.

In this sense, many research works have directed their themes towards the use of eco-materials integrating substitute materials such as Typha [5-7], straw, kenaf, flax, millet stalks, etc.

Indeed, in Benin our rivers are often full of many plant materials such as the stems of quackgrass, Typha, etc..

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This country also has large deposits of clay, earth bar, kaolin, gravel, etc..

In our regions of Benin, the stem of Typha "Domengensis" has been used since the time of our ancestors in the manufacture of mats, traditional mattresses called "ako-zan" [8-15]. It is also used in the installation of false ceilings and ornaments of dwellings in the suburbs.

Its integration into the design of composite construction materials therefore offers it a much more beneficial recovery solution than in the past, given that these Typha stems invade our lakes, lagoons and lake environments, thus causing a real threat to the environment ecosystem and the social, economic and health balance.

Faced with these problems, attempts have been made to eliminate typha (mechanical, chemical, biological methods, etc.). These methods of control used, not having given very satisfactory results, the present work proposes a solution of protection of our ecosystem and an energy recovery of the typha by its integration in the concession of innovative eco-materials.

For this reason, the present work entitled "Development of a Composite Eco-Material Based on Typha from a Clay Matrix" has the general objective of developing an agro-material based on Typha taken in a matrix of clay.

2. Material and Methods

The development of the composite agro-material defined above intended for the manufacture of the partitions of the dwellings, will require different types of materials used in various devices.

2.1 Materials

2.1.1 Typha

The stem of "typha" is a monocotyledonous herbaceous plant, it belongs to the Typhaceae family, it is very widespread in tropical and temperate zones, under several species. The species that grows in Benin is the "Typha Domingensis", it is found much more in the coastal regions and along the courses of southern Benin.

The typha plants used were taken from Ekpe in the commune of Seme-Podji in southern Benin (Fig. 1).

This invasive plant is entirely composed of 71.6% volatiles, 20.5% fixed carbon, and about 7.9% ash. Humidity represents 66.96% of the mass of this plant. When air-dried for 7-10 days, this plant can lose more than 80% of its moisture. The dry matter represents only 27% [6].

2.1.2 Clay

Clay is a mineral available in Benin, in the regions of Oueme-Plateau, Zou, Mono-Couffo and in the northern regions. It is used in pottery for the manufacture of terracotta art objects. In construction, clay as a local material is used in its "fired" form. Moreover, its use as a binder in the manufacture of briquettes as a composite material does not date back a long time. The one used for the development of the eco-material is taken from the Dangbo site (southern Benin) (Fig. 2).

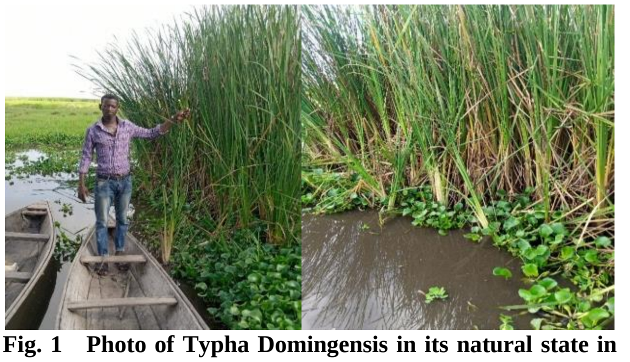

Fig. 1 Photo of Typha Domingensis in its natural state in the Seme-Podji region (Benin).

Fig. 2 Photo of clay sampling on the Dangbo site (Benin).

2.1.3 Devices Used

For the development of the composite material intended for dwellings, different devices were used.

(i) An oven

A GM brand oven is used to dry the typha aggregates, it is set at 105 ℃ for 24 h during the various tests (Fig.3).

(ii) An electronic scale

A Dawood brand electronic balance was used for the rapid weighing of the different material samples with an accuracy of 0.1 g. It offers a measurement range of 1g to 3,000 g allowing defining various proportions of typha and binder for the formulation of the samples of material to be tested (Fig. 4).

(iii) A mold

In this work, the mold used has the dimensions 4 cm × 4 cm × 16 cm (Fig. 5).

(vi) A mill

A crusher with a power of 0.75 kW, was used to reduce the typha stems into powder to a size of less than 3.15 mm (Fig. 6).

Fig. 3 Photo of the oven.

Fig. 4 Photo of the electronic scale.

Fig. 5 Photo of the mold.

Fig. 6 Photo of the mill

2.2 Methods

The different methods used for the formulation of briquettes based on typha and clay are presented.

2.2.1 Method of Obtaining Briquettes

2.2.1.1 Preparation of Typha Particles

(i) Harvesting and drying typha stems

Harvest: Typha stems were harvested at maturity as shown in photo of Fig. 7.

Drying: These rods are dried for 2 to 3 weeks in the sun. After this natural drying, the stalks are chopped into small aggregates with a size of about 1 cm × 2 cm as shown in the photo in Fig. 8. Then the aggregates are stored in an oven at a temperature of 105 °C for 24 h.

Fig. 7 Photo of *Typha domingensis* harvest.

Fig. 8 Photo of cut and dried Typhas.

(ii) Crushing and sieving

The cut and dried typha stems are then ground into fine and medium particles using a Vicking type knife grinder. The grinder is equipped with teeth that reduce particles. The particles obtained have a size between 0.630 mm and 8 mm (Fig. 9).

2.2.1.2 Preparation of the Binder

The material used as a binder in the manufacture of briquettes is clay. The binder production process has the following main phases:

1. Extraction of clay from the quarry;
2. Transport to the place of production;
3. Clay drying in the sun for a week, then stored in an oven at a temperature of 105 ℃ for 24 h;
4. Clay grinding.

2.2.2 Sieving Typha Particles

2.2.2.1 Experimental Protocol

Before starting the sieving of the particles, the mass of the Typha to be sorted is determined after knowing the maximum diameter.

The maximum diameter is the diameter of the sieve immediately greater than the sieve having kept at least one grain. Here $D_{max} = 10$ mm, we can therefore know the mass to be serialized using the following framework:

$$0.2D_{max} \leq m \leq 0.6D_{max} \quad \text{with} \quad \begin{cases} D_{max} en mm \\ m en Kg \end{cases}$$

that is 2 kg $\leq m \leq$ 6 kg. The mass taken is m= 2,500 g or 2.5 kg.

Fig. 9 Photo of crushed and steamed Typhas.

Fig. 10 Photos of a series of sieves and measurement of particles typha.

2.2.2.2 Principle of the Sieving Test

The test consists of separating the agglomerated grains from a known mass of material by sieving once dried, using a series of sieves and successively weighing the accumulated residue on each sieve. The accumulated oversize mass on each sieve is added to the total dry mass of the sample submitted for analysis. The purpose of the particle size analysis is to characterize the dimensional classes of the grains of an aggregate, by determining their mass proportion. So the largest sieve size is 125 mm and the smallest is 0.063 mm. During the test, two parameters are determined: the refusal consisting of grains which are retained by the sieve and the sieve which corresponds to the portion of aggregate which passes through the sieve.

2.2.2.3 Execution of the Test

- Arrange in decreasing order of mesh size with bottom and lid.
- Pour the mass (m) into the column of sieves with openings: 8 mm; 6.30 mm; 5 mm; 3.15 mm; 2.5 mm; 1.25 mm; 1 mm; 0.630 mm.

- Agitate the column, manually or mechanically, then take the sieves one by one, start with the one with the largest opening and manually agitate each sieve, ensuring that there is no loss of material, using the bottom and the lid. Under no circumstances should the operator force the gravel with his hand to help it pass through the sieves.
- Transfer all the material that passes through each sieve to the next sieve in the column before continuing the operation with this sieve.
- Weigh the oversize at the level of the first sieve that retained part of the sample and record R1.
- Carry out the same operation for the sieve immediately below, and note the mass of the refusal R2.
- Continue the same operation for all the sieves which are in the column, in order to obtain the mass of the various fractions of materials retained and note these masses, R3, R4,... Ri,...Rn.
- Weigh the sieved material, remaining in the bottom if necessary, and enter the value of its mass.

2.2.2.4 Preparation of the Slip

Indeed to implement the "slip" (clay-water mixture brought to an appropriate consistency to serve as a binder for a fiber composite), the clay which will serves as a binder for the material is first crushed then sieved (mesh sieve 2 mm) and dried to remove grains of sand. This is to facilitate the dissolution of the grains in the water. Then the clay is poured into the container with water. Then, a mechanized mixing (mixer) is carried out. The mechanical action of the mixer makes it possible to distribute the clay evenly and lead it to its dissolution. This process also makes it possible to dissolve the clods of earth (spherical agglomeration of earth) which forms during the clay-water mixture.

Fig. 11 Photo of Typha particle sieving according to sieve size.

2.2.3 Formulation of the Material

2.2.3.1 Binder-Typha Mixture

This mixture consists of combining the binder with the Typha particles so that they are completely covered with clay. Therefore, the plant particles are linked together and make it possible to obtain a heterogeneous material whose properties result from those of these constituents (clay, Typha fibers). In order to guarantee a homogeneous distribution of the slip on the particles, the mixing is carried out manually.

2.2.3.2 Formulation and Manufacture of Test Specimens

Dosage consists of determining the portion of each constituent (clay, Typha and water) that must be incorporated into a mixture for a material with the desired properties.

Typha stem particles (PTT) are mixed with clay and water in a Hobart-type mixer for 15 min to obtain a homogeneous mixture of total mass M_m.

For this, we started to take as the proportions of the binder of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, to manufacture the test specimens. The rate of clay noted (T_A), introduced into the mixture is written:

$$T_A = \frac{M_A}{M_A + M_T} \times 100 \quad (1)$$

with M_A:clay mass,M_T:total particle mass of typha stems.

The water content of the mixture (H_m) is adjusted by adding a quantity of water defined as follows:

$$H_m = \frac{M_e + [(M_T + H_T) + (M_A + H_A)]}{M_m} \quad (2)$$

With

$$M_e = M_m \times H_m - [(M_T \times H_T) + (M_A \times H_A)] \quad (3)$$

with M_e: the mass of water added (in g); M_m: total mass of the mixture (in g);

H_m: Humidity of the desired mixture; M_T: total particle mass of typha stems (in g), H_T: Particle humidity of typha stems; M_A: mass of clay introduced (in g); H_A: Clay humidity.

2.2.3.3 Execution of the Test

- Mix a quantity of clay with the Typha according to the proportions.
- Knead the mixture.
- Start by molding the dough between the moulds.
- Unmold the sample after 24 h.

The specimens obtained with the proportions of the binder of 0%, 10%, 20%, 30%, 40%, 50%, cannot undergo the thermal and mechanical tests because after drying, one notes the bursting and the delamination of these test tubes (Fig. 12).

Fig. 12 Photos of some specimens.

Fig. 13 Samples obtained with 80% of the binder.

Fig. 14 Photos of specimens obtained after 21 days.

3. Result and Discussion

3.1 Particle Size Result

The particle size analysis carried out in the laboratory on typha stems by dry sieving gives the results which are recorded in Table 1.

From the data in this table above, the particle size analysis curve is plotted by plotting on the abscissa the values of the openings of the sieve meshes (1st column) and on the ordinate the percentage by mass of the typha particles passing (5th column) through the sieve mesh openings.

3.2 Interpretation of Particle Size Distribution

The particle size distribution of the particles as a percentage of the total mass obtained by sieving allows us to classify them into three classes:

Class 1: fine particle size $\epsilon([0.630 - 0.125\ \text{mm}]\ )$

Class 2: particles of intermediate size $\epsilon([0.125 - 3.15\text{mm}])$

Class 3: large particles $\epsilon([3.15 - 8\ \text{mm}])$

Each of its categories will enter into the composition of a formulation for the manufacture of briquette samples, i.e. test specimens according to the following categories:

G-categories:

G_{1H} or G_{1D} (80% Typha class 1 + 20% Houeyogbe clay or 20% Dangbo clay)

G_{2H} or G_{2D} (80% Typha class 2 + 20% Houeyogbe clay or 20% Dangbo clay)

G_{1H} or G_{3D} (80% Typha class 3 + 20% Houeyogbe clay or 20% Dangbo clay)

Categories G′:

G'_{1H} or G'_{1D} (90% Typha class 1 + 10% Houeyogbe clay or 10% clay)

G'_{2H} or G'_{2D} (90% Typha class 2 + 10% Houeyogbe clay or 10% clay)

G'_{3H} or G'_{3D} (90% Typha class 3 + 10% Houeyogbe clay or 10% clay)

The different types of briquettes made are summarized in Table 2.

Table 1 Data from dry sieving.

Opening	Partial refusal in (g)	Cumulative refusal in (g)	%Cumulative refusal	%passing
10	0	0	0	100
8	0.2	0.2	0	100
6.30	5.5	5.7	0.23	99.77
5	7.4	13.1	0.54	99.46
3.15	63.1	76.2	3.13	96.87
2.5	71.4	147.6	6.07	93.93
1.25	306	453.6	18.66	81.34
1	285	738.6	30.39	69.61
0.630	362	1,100.6	45.28	54.72
Sieve bottom	1,330	2,430.6	-	-

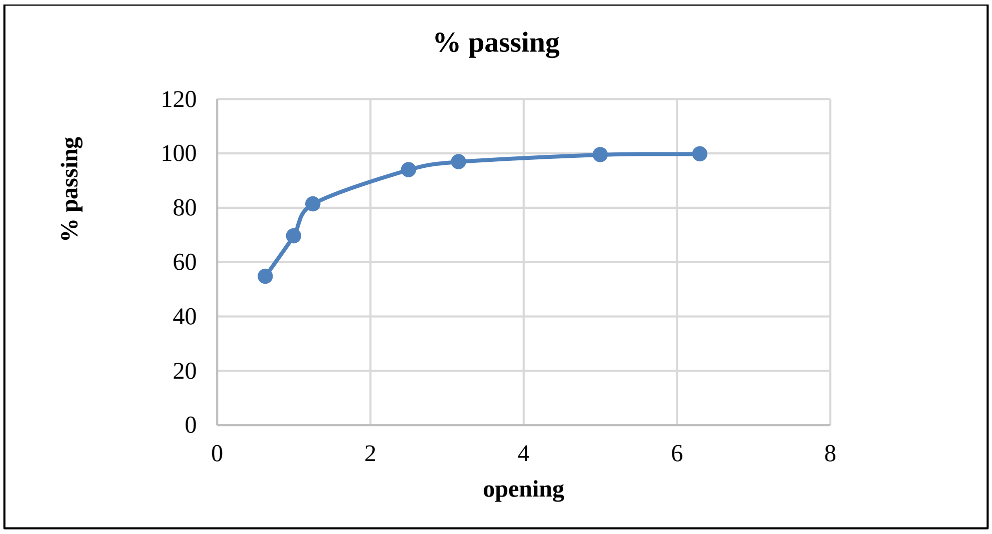

Fig. 15 Particle size analysis curve.

Table 2 Differenttypes of briquettes made.

Class of typha	80% Houéyogbé clay and 20% typha particles	80% Dangboclay and 20% typhaparticles	90% Houéyogbé clay and 10% typha particles	90% Dangboclay and 10% typha particles
Class 1	G_{1H}	G_{1D}	G'_{1H}	G'_{1D}
Class 2	G_{2H}	G_{2D}	G'_{2H}	G'_{2D}
Class 3	G_{3H}	G_{3D}	G'_{3H}	G'_{3D}

Fig. 16 Photos of selected briquettes.

4. Conclusion

This work has enabled us to develop a prototype of a biodegradable brick, which is a 100% natural bio-based composite, produced locally based on typha and clay. Clay soil and typha stems are available locally. Typha stems have a low economic value according to traditional use in southern Benin. The massive use of these materials in construction will now make it possible to enhance them ecologically. This is perfectly in line with the policy of energy saving and promotion of our local materials in Benin.

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