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Physico-mechanical characterisation of the composite of clay and grown typha fiber

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ABSTRACT: This article looks at the use of local materials for sustainable construction, focusing on a composite combining Sebikotane clay and ground Typha australis fibers. The study aims to overcome the limitations of clay, such as swelling and shrinkage, by incorporating natural fibers as stabilizers.
Particle size analysis reveals that Sebikotane clay, the base material studied, is made up of 48% clay, 10% silt, and 42% fine sand. Atterberg limit tests confirm significant plasticity, while tests carried out on clay-Typha composites with fiber incorporation rates varying from 0 to 8% show a compressive strength of between 1.38 and 2.07 MPa.
The addition of fibers significantly reduces volume shrinkage (up to 88.88% with 8% fibers) but is accompanied by an increase in loss on ignition, reaching 17.6% with 8% Typha.
Analysis of the results shows that to ensure optimum performance in construction, particularly in terms of mechanical strength and dimensional stability, it is advisable to limit the incorporation of Typha fibers to a maximum of 4%.

KEYWORDS: clay, typha, resistance to compression, volumetric shrinkage, fire loss, water absorption.

1 INTRODUCTION

Promoting local materials in the construction sector is a major challenge from a sustainable development perspective. Because of its abundant availability and intrinsic properties, clay is a promising building material. However, its use is limited by its swelling and shrinkage characteristics, which compromise the stability and durability of structures. To overcome these limitations, mechanical stabilization is essential.

According to Danso et al [1], three main approaches to stabilizing materials have been identified: the use of natural fibers, the addition of minerals (cement or lime), or a combination of the two. In this context, Typha australis, a renewable natural resource, is being considered as a clay reinforcement to improve its performance while meeting environmental and economic requirements.

The aim of this work is to characterize the physical and mechanical properties of a clay-typha composite with a view to its use in construction. The study is based on an analysis of the properties of the raw materials (clay and Typha australis), followed by an assessment of the physical-mechanical performance of the composites. The results will be used to formulate recommendations for optimizing the applications of this material in the context of sustainability.

2 MATERIALS AND METHODS

2.1 PREPARATION OF RAW MATERIALS

The clay used in this manuscript comes from the town of Sébikotane, 24 km from Thiès. It was sifted using a 1mm mesh sieve.

The typha australis used was obtained from the town of Richard Toll in the Saint-Louis region. It was dried for a fortnight, then cut with a machete and ground by machine. A 10 mm mesh sieve was used to collect the bystanders. Figure 1 shows the crushed typha and the clay sieve using a 1 mm sieve.

Fig. 1. Typha australis and clay

2.2 GEOTECHNICAL IDENTIFICATION TESTS

2.2.1 NATURAL WATER CONTENT (W)

The natural water content is obtained by oven drying a quantity of soil at 105°C. It is the ratio of the mass of water evaporated to the mass of dry soil (solid grains).

Determination of the natural water content is based on the following formula [2]:

$$W(\%) = \frac{m_h - m_s}{m_s} x100$$

Where m_h: the mass of the soil sample in its natural state; ms: the mass of this soil sample after oven drying at 105°C for 24 hours; $m_h - m_s$ = mass of water.

2.2.2 PARTICLE SIZE ANALYSIS

Granulometric analysis is a geotechnical test designed to determine the size and percentage of aggregates in a material to classify the soil. It is carried out by sieving if the diameter of the samples is greater than 0.08mm NF P94-060 [3] and by sedimentation if the dimensions of the samples are less than 0.08mm NF P94-057 [4]. For our clay material, we used both identification techniques.

2.2.3 ATTERBERG'S LIMIT

The Atterberg limit was used to determine the plasticity of our soil.

There are two types of Atterberg limit (the liquid limit WL and the plastic limit WP). The liquid limit corresponds to the water content of a reworked soil at the transition point between the liquid and plastic states.

The plasticity limit is the water content of a reworked soil at the point of transition between the plastic and solid states. These limits are determined on the fraction of soil passing through the 400µm sieve NF P94-051 [5].

The difference between the liquid limit and the plastic limit gives the plasticity index IP. This index defines the extent of the plastic domain. It is determined by the following equation:

$$IP = WL\text{-}WP$$

2.2.4 METHYLENE BLUE TEST

The blue test enables us to assess the quantity and quality of clays in our soil.

According to standard NF P94-068 [6] the principle consists of measuring the quantity of methylene blue that can be adsorbed by the material suspended in water.

VBS is expressed in grams of blue per 100 g of dry material.

For materials with a Dmax of less than 5 mm, the methylene blue value is calculated by:

$$\text{VBS} = \frac{m_{BM}}{m_0} \times 100$$

where m_{BM} is the mass of blue introduced (10 g/l solution).

$$m_{BM} = \text{V} \times 0{,}01$$

m_0: dry mass of the test sample.

V: volume of blue introduced.

The specific surface area can be determined from the quantity of methylene blue injected into the clay minerals suspended in an aqueous solution until saturation by adsorption. It is calculated from the following equation [7]:

$$S_s = \frac{m_{BM}}{m_0} \times \frac{A_v}{319{,}86} \times A_{MB} \text{ in}(m^2/g)$$

where A_v: Avogadro number (6,02 x 10^{23} atoms/mol);

A_{MB}: area covered by a molecule of methylene blue (130 $Å^2$)

2.3 Is The Molecular Weight Of The Dye With The Chemical Formula

2.3.1 Absolute Density Of Solid Grains

This test aimed to determine the specific weight of our clay soil without its porosity.

In accordance with standard NF P 94-054 [8], this is determined using a water pycnometer.

The measurement procedures are as follows:

- The mass (m_1) of the pycnometer alone is weighed.
- The mass of the pycnometer containing the sample is m_2
- The pycnometer containing the sample is filled to the mark with distilled water. The whole mixture is shaken to obtain a homogeneous mixture and weighed, after allowing any air bubbles to escape (m_3);
- Finally, the pycnometer is emptied, cleaned, dried and filled with water up to the stopper mark, then weighed (m_4).

The absolute density is obtained from the following relationship:

$$\gamma_s = D \frac{m_2 - m_1}{m_4 + m_2 - m_1 - m_3}$$

where D: the relative density of distilled water at a given temperature.

Figure 2 shows the pycnometer filled with water.

Fig. 2. pycnometer + water

2.3.2 APPARENT DENSITY

The apparent densities of our raw materials clay and Typha fiber have been determined. The test consists of weighing the sample in a known volume and deducing the mass of the test tube. This test is carried out under standard NF EN 1097 – 3 [9]. The value of the apparent density is given by the relationship:

$$\rho = \frac{m}{V}$$

2.3.3 WATER ABSORPTION

Typha is a biobased material with hydrophilic behaviour. To determine its water absorption kinetics, we dried some of its weight in an oven for 24 hours until it had a constant weight. We then took 20 g of typha and immersed it completely in water to evaluate its water absorption kinetics at different times.

2.4 PRODUCTION OF TEST SPECIMENS

The samples are made from a mix of raw materials (clay + ground typha fiber) to which water is added for mixing. The percentage of ground typha fiber incorporated varies from 0 to 8%, with steps of 2%. The raw materials are dry-mixed to obtain a homogeneous mixture. The quantity of water added for mixing was determined using the general formula: E = 0.25 A + 0.27 B where A and B are the respective mass percentages of clay and typha fiber [10].

Cylindrical samples with a diameter of 11cm and a height of 22 cm and prismatic samples with a size of 4x4x16 Cm^3 were produced for compression and bending tests respectively. They were then dried in the open air and out of the sun until their mass had completely stabilized. Figures 3 and 4 show the various specimens obtained.

Fig. 3. Cylindrical test tubes

Fig. 4. Prismatic test tubes

2.5 PHYSICAL AND MECHANICAL CHARACTERISATION

Construction materials are often subjected to various mechanical and physical phenomena, such as tensile and compressive loads, as well as phenomena due to the instability of their volumes, such as shrinkage. Compression and tensile tests, as well as tests of the physical behaviour of our materials in the face of fire and shrinkage phenomena, are therefore necessary.

2.5.1 MECHANICAL COMPRESSION TEST

Compressive strength is measured by uniaxial compression of straight cylinders of revolution with a cross-section S and a height twice their diameter. In this test, our cylindrical specimens are placed between the platens of a press and the axial force is increased until the specimen breaks. The test set-up is illustrated in Figure 5.

The maximum value F of the force is used to calculate the axial compressive strength of the material according to the following relationship [11]:

$$R_c = \frac{F}{S}$$

R_c = Resistance in compression (in MPa)

S = Cross-section of specimen (in mm^2)

Fig. 5. Simple compression test device

2.5.2 FLEXION TENSILE TEST

The test is carried out on a compression press, using lower support rollers spaced three times the square cross-section of our prismatic specimens, and upper support rollers spaced once the prism. These apply the load from the press plate to the specimen. The experimental set-up is shown in Figure 6.

The three-point bending tensile strength of a prismatic concrete specimen with a square cross-section of side 'a' subjected to a breaking load would then be: $R_{fd} = \frac{1.8F}{a^2}$ [12].

Fig. 6. Testing device for 3-point bending

2.5.3 FIRE LOSS TEST

Loss on ignition was determined by measuring the mass loss of our prismatic samples between the drying and firing stages. Firing took place in a NABERTHERM electric oven with a maximum temperature of 3000℃ (Figure 7). Our well-dried specimens were baked for 1 h 30 min. The maximum temperature reached was then 900°C. The oven was then switched off and allowed to cool to room temperature.

Fig. 7. NABERTHERM electric oven

Fig. 8. Internal view of the oven after the test tubes have been fired

2.5.4 VOLUMETRIC SHRINKAGE

A volumetric shrinkage study was carried out on our cylindrical specimens before and after drying for 21 days.

The volume shrinkage R_V expressed as a percentage is calculated according to the following formula [13]:

$$R_V = \frac{V_H - V_S}{V_H} x100$$

Where V_H: wet volume of the sample and V_S: dry volume of the sample.

3 RESULTS AND DISCUSSION

3.1 NATURAL WATER CONTENT

The results of the natural water content of the clay sample are presented in Table 1.

These results are the average of the two tests.

Table 1. Natural water content of the clay sample

Tests	Wet mass in g	Dry mass in g	Water content in %
1	409,67	382,12	7,21
2	412,85	380,78	8,42
			Average of water content =7,81

3.2 PARTICLE SIZE ANALYSIS

The results of the particle size analysis on our clay material are shown in Figure 9.

They show that the soil used in this report is composed of 48% clay, 42% sand and 10% silt, and more than 65% of the grains by mass pass through the 80 µm sieve.

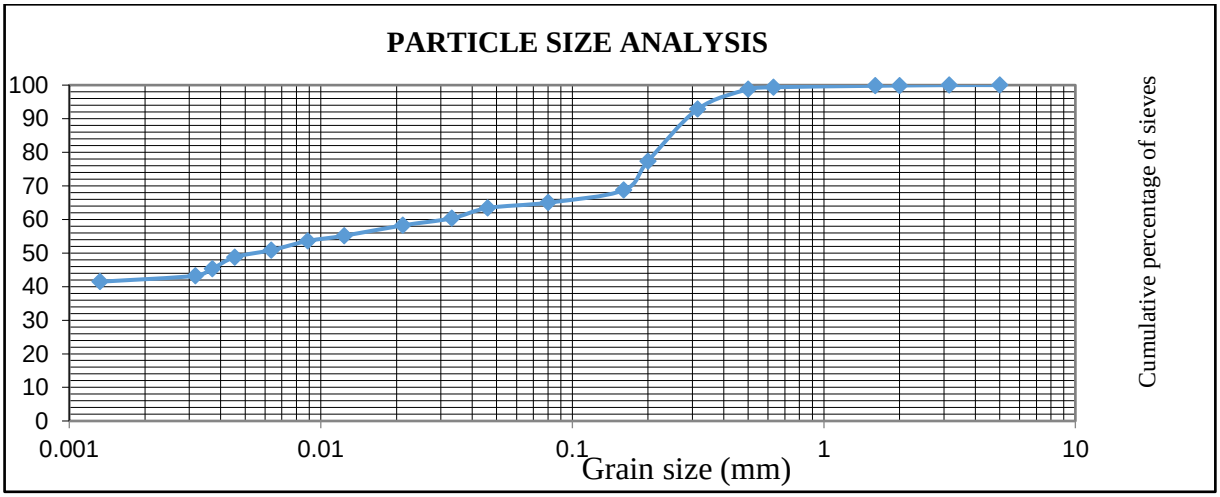

Fig. 9. Clay particle size distribution curve

3.3 ATTERBERG'S LIMIT

The liquid limit found for the clay is 39.71%, its plastic limit is 19.43%.

Its plasticity index is 20.28%. These results show that the clay used in this work is plastic [14].

3.4 TEST OF A SOIL WITH METHYLENE BLUE

The blue test on our soil material gives a value of 4.8. This result shows that our soil is silty clay [15].

Using the blue test result, we determined the specific surface area of our clay material which gives a value equal to $117 m^2/g$.This specific surface result shows the presence of illite in the clay material [16]. Therefore, the clay used has a moderate swelling potential [17].

3.5 THE ABSOLUTE AND APPARENT DENSITY OF RAW MATERIALS

We carried out three tests to determine the absolute and apparent density of our materials. The results presented are the average of the three tests. The absolute density of the clay is 2,56 g/Cm^3, its apparent density is 1,14 g/Cm^3. The results show that clay is made up of light particles [18].

The apparent density of the typha obtained is 0,056g/Cm^3.

3.6 WATER ABSORPTION BY TYPHA FIBER

We used the formula below to determine the rate of absorption of typha fibre in different times. The procedure is as follows:

$$A(t)\% = \frac{m(t) - m_i}{m_i}\ x100$$

with m(t) mass of the sample at time t, m_i mass of the initial sample.

The results of the water absorption kinetics are presented in Table 2.

Table 2. Absorption rate of typha fiber

Duration in (min)	mass (g)	absorption %)
0	20	0
5	55	175
30	73	265
1440	93	365

The results of the water absorption kinetics of our typha fiber are comparable to those of Ababacar Ali's work [8] on rice straw.

3.7 Compression And Flexural Strength Results

Table 3 shows the proportions of clay and typha fiber mixed for the compression and bending tests.

Table 3. Mix compositions (Clay + Typha)

Component / Sample	Crushed fibers of typha in % of mass	Sebikotane clay in % of mass
E0	0	100
E2	2	98
E4	4	96
E6	6	94
E8	8	92

The results of the compressive strengths (R_C) are shown in Figure 10.

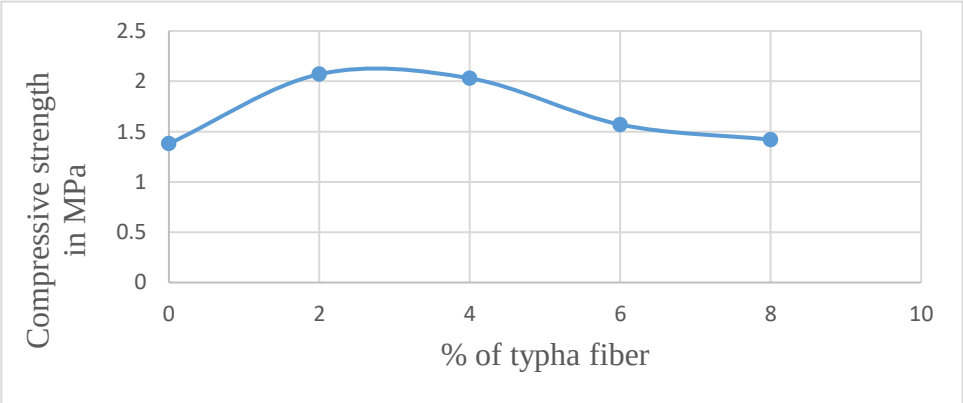

Fig. 10. Evolution of compressive strength as a function of % of typha fiber mixed with Sebikotane clay

The results in Figure 10 show an increase in compressive strength from 1.38 to 2.07 MPa when the percentage of typha fiber incorporation is increased from 0% to 2%. We then observe a progressive decrease in the compressive strength of the composite from 2.03 to 1.42 MPa when the addition of typha fiber to the clay is increased from 4% to 8%. The decrease in the compressive strength of the composite can be explained by the effect of a significant decrease in the density of the composite when the addition of the fiber reaches a certain quantity.

However, at 8% typha, despite a reduction in the compressive strength of the composite, it remains higher than that found for pure clay. This proves the good cohesion between the clay and the typha fiber.

In this case, the typha fiber is used to reinforce the pure clay. This prevents the appearance of cracks when the typha fiber clay composite dries.

Our compressive strength results are in the same range as those for the gum arabic clay composite produced by Ababacar Ali [19].

The bending tests carried out on the prismatic specimens gave weak results, so the machine did not display them.

These results are comparable to those of the typha clay powder composite produced by Younouss Dieye [20]. The results of the physical properties of clay show that its specific weight is low compared to other construction materials. This low value is because clay contains a high percentage of pores. This porosity harms mechanical properties, particularly flexural strength.

Several standards, such as the Australian standard, consider a zero tensile strength for clay due to a lack of testing. In New Zealand, the standard suggests a value of 0.1 MPa for tensile strength, or deducted from compressive strength in the absence of testing [21].

3.8 FIRE LOSS RESULTS

We determined the loss on ignition of our prismatic specimens for different typha fibers incorporated in unfired clay bricks using the following formula [13]:

$$Fire\ loss\ \% = \frac{m_{seche} - m_{cuite}}{m_{seche}}\ x\ 100$$

The results obtained are summarised in Figure 11.

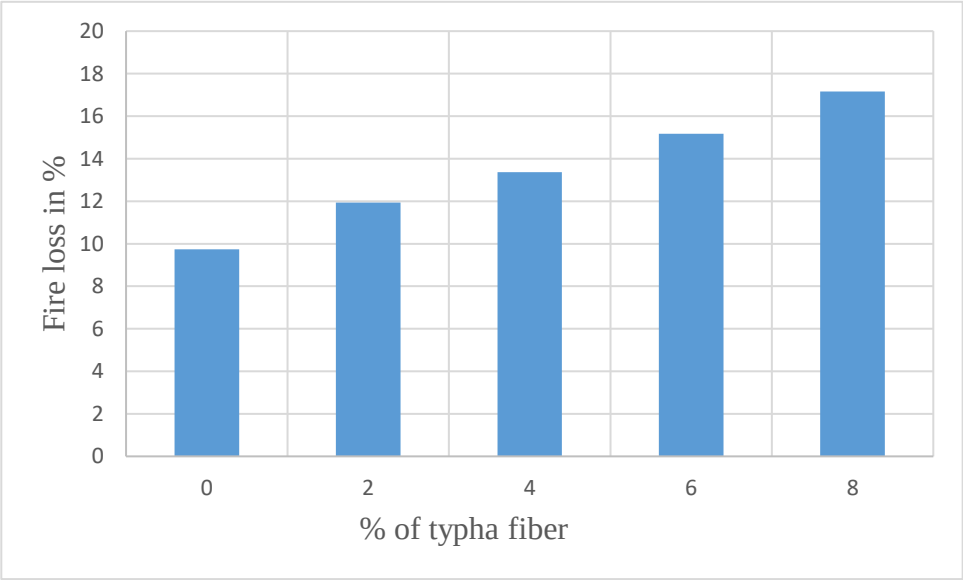

Fig. 11. Loss on ignition of samples manufactured with different percentages of typha

The results in Figure 11 show that the loss of ignition of our materials increases with the incorporation of the pore-forming agent referred to here as typha fiber. The respective values are 9.74; 11.94; 13.36; 15.17 and 17.6% when the percentage of incorporation of the fibre increases from 0 to 8%.

The addition of fiber to the clay mixture creates porosity in the system during the firing process through dehydroxylation and carbon decomposition. This void formation leads to a reduction in mass, as the air is lighter than the clay and fibers. Therefore, for the material to retain its good fire performance, its loss on ignition must be less than 15% [22]. In our study, the incorporation of 6% fiber in the clay material exceeds the standards.

3.9 VOLUMETRIC SHRINKAGE

Table 4 shows the volumes of cylindrical specimens measured in the dry state. These results are obtained by averaging the three measurements on each type of sample.

Table 4. Average volumes of samples measured after 21 days of drying

Sample	E0	E2	E4	E6	E8
Mass in kg	3,17	3,03	2,85	2,80	2,76
dry volume of samples in cm^3	1591,41	1697,38	1772,54	1865,45	2015,22
Volumes of wet samples in cm^3	2090,73	2090,73	2090,73	2090,73	2090,73

The data in Table 4 and the volume shrinkage formula have enabled us to plot the volume shrinkage curve as a function of our samples.

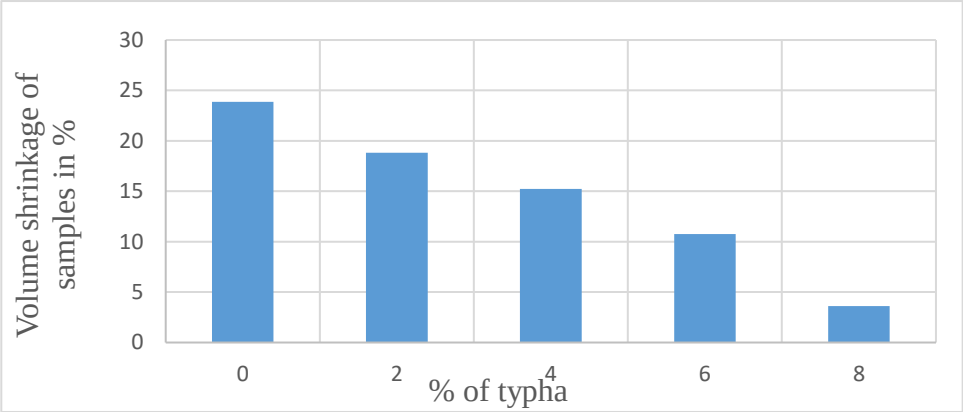

Fig. 12. Volume shrinkage on drying for different percentages of typha on unbaked clay material

The results in Figure 12 show that the shrinkage of the material during drying decreases with the incorporation of the quantity of ground typha fiber. At 0% fiber, the shrinkage is 23.88% and at 8% fiber, it is 3.61%.

When clay is mixed with water, because of its porosity, its internal pores are filled with water. This causes its volume to swell. During the drying process, the water evaporates from the pores and is replaced by air, giving rise to the phenomenon of drying shrinkage.

Secondly, typha fiber is hydrophilic, so it absorbs a certain amount of water during mixing. This water, which has become bound, does not take part in evaporation, which explains the reduction in volume shrinkage as a function of the percentage of fiber.

In this report, with 8% incorporation of typha fiber, we obtain a reduction in the rate of volume shrinkage of 88.88% compared with the rate of shrinkage of the pure clay material.

4 CONCLUSION

This study is part of an initiative to develop clay and Typha australis for use in sustainable construction. Analysis of the characteristics of Sebikotane clay confirmed its plasticity and favourable composition in terms of light particles. Tests on clay-typha composites have shown that the incorporation of fibers significantly improves certain mechanical properties, by reducing volume shrinkage by up to 88.88% with 8% fibers. However, fire performance decreases above 6% fiber addition.

For optimum application, it is recommended that Typha fiber incorporation be limited to a maximum of 4%, to ensure a compromise between mechanical strength and dimensional stability. Finally, further research into the thermal properties of composites is needed to refine their design and broaden their range of applications, while meeting sustainability and energy performance requirements.

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