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***Journal of Scientific and Engineering Research*, 2021, 8(12):123-128**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Characterization of cement-reinforced Typha-clay composites

***Ibrahima DIAW[1,2], Mactar FAYE[1,2], Seckou BODIAN[2], Vincent SAMBOU[2]**

[1]Efficiency and Energetic Systems Research Group, Alioune Diop University of Bambey, BP 30 Bambey,Senegal
[2]Laboratoire Eau, Energie, Environnement et Procédés Industriels (LE3PI), Cheikh Anta Diop University of Dakar, BP5085 Dakar-Fann, Senegal

Abstract This paper contributes to the development and characterization of sustainable and environmentally friendly building materials. Bio-based materials were developed with Typha fiber and clay binder stabilized by cement. The influence of the addition of cement on the mechanical and thermal properties was studied. The evaluation of mechanical properties was done by determining the compressive strength and the evaluation of thermal properties by the thermal conductivity of the samples. Results show that compressive strength values range from 0.15 to 0.89 MPa. Results also show that cement addition has no significant impact on thermal conductivity of sample. Addition of cement improves the mechanical properties but doesn't influence the thermal properties of the composites.

Keywords Typha fiber, compressive strength, Thermal conductivity, hot box

Introduction

In a context of sustainable development and reduction of environmental impact of the building sector, bio-based building materials are increasingly developed. Energy consumption of the building sector and its impact on the environment has been increasing in recent decades. According to Wei et al. [1], the overall contribution of energy consumption in buildings has reached figures between 20 and 40% and represents about one third of greenhouse gas emissions. According to Diaw et al. [2], the building sector accounts for 44% of final energy consumption, 40% of greenhouse gas emissions and 40% of waste produced on the planet, hence its strong impact on the environment. Dièye et al. [3] indicate that the energy consumption of the building sector represents 25 to 30% in West Africa and 54.7% in Senegal and contributes to 49% of CO_2 emissions in Senegal. The building sector is one of the most energy-intensive sectors. Its impact on the environment is not negligible. Given this high energy consumption, bio-based construction materials aimed at reducing energy consumption in the building sector are increasingly developed. These materials are composed of plant fibers and a binder. Fibers are renewable and allow the storage of carbon during their growth [4]. These fibers offer many advantages. They are light, insulating and less expensive than glass fibers, however, the manufacturing of a binder increases the energy consumption of the building sector and its environmental impact. Clay is a traditionally material used in construction. It is an ecological material, sustainable, with low environmental impact and has a good thermal inertia [5-6]. Several works have focused on the valorization of clay as construction material. However, to improve thermal properties of clay, several authors have favored the addition of plant fibers on clay materials. In this perspective Ouakarrouch et al. [6] studied the impact of addition sisal fibers on the thermal properties of clay bricks. Results show that addition of sisal fibers significantly reduces the thermal conductivity of composites. Lamrani et al. [5] studied the effect of adding date palm fibers, straw fiber and olive waste on the thermal properties of pure clay. Results show that addition of these components improves the thermal properties of clay composites. Azhary et al. [7] investigated the thermal properties of clay-wheat straw composites to improve their energy efficiency. Results show that addition of straw fibers improves the thermal properties of the composites. The author concludes that using straw fibers can minimize the thermal losses in a building. In order to reduce environmental impact of hemp concretes, Mazhoud et al. [4] conducted a study to replace the lime-based binder by natural clay. A comparison is then made between thermal properties of hemp-clay composites and those of hemp-lime composites. Results show that thermal conductivity of hemp-clay composites is lower than that of hemp-lime composites. Labat et al. [8] studied the thermal performance of straw-clay composites. Results show that thermal conductivity of the composites increases with density. Most of these studies have focused on improvement of thermal properties clay by incorporating vegetable fibers, whereas biosourced materials often have low mechanical performances. Nevertheless, some authors have evaluated the mechanical properties of clay-plant fiber composites. Fernea et al. [9] studied the thermomechanical properties of hemp-clay composites. The results show that the thermal conductivity increases with the density of the composites. The compression and flexural results range from 0.1 to 1N/mm^2 and 0.1 to 0.5 N/mm^2, respectively. Kouakou et al. [10] studied the influence of coir fibers on the mechanical behavior of cement-stabilized earth blocks. Results show that addition of coconut fiber improves mechanical properties, delays cracking and increases ductility of the material. Djohore et al. [11] studied the effect of addition of potash-treated coir fiber on the mechanical performance of clay-cement building materials. Results show that addition of fiber improves the mechanical properties of cement-stabilized clay mortars. The mechanical performances are more important when these fibers are treated with potash. Limami et al. [12] studied the mechanical performances of reinforced unfired clay bricks with recycled Typha-fiber waste as a construction material additive. Different mass percentage of Typha (0%, 1%, 3%, 7%, 15% and 20%) were added. Results shows that compressive strength decreases with increasing Typha content. Typha-clay materials have already been studied by Dièye et al. [3] and Niang et al. [13]. The aim of this study is to improve mechanical properties of Typha-clay composites by incorporating different amounts of cement. Next part of this manuscript discusses the materials and experimental methods. The third part presents the results of the study and the last part presents a conclusion to this work.

Materials and Methods

Material

Fibers used in this study come from Typha plant. The Typha plant was harvested and exposed to the sunlight for two weeks. Fibers were obtained by a process of transformation of the plant with a hammer mill. They were then sieved to remove dust (powder) and fibrils (small fibers). Figure 1 and Figure 2 presents respectively the aspect and granulometric curve of Typha fiber.

Figure 1: Typha fiber

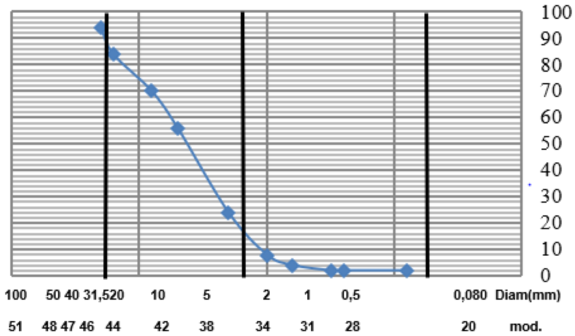

Figure 2: Granulometric curve of Typha fiber

A clay-based binder was used in this study. The clay was manually crushed with a hammer and then sifted with a 1 mm diameter sieve. Figure 3 presents the Thicky clay aspect. This clay is produced in a quarry located in the region of Thies, precisely in a locality named Thicky. It is composed of quartz, kaolinite, illite and calcite [14]. According to Niang et al. [13] this soil is clayey with a plasticity index of 31.03%. Commercially available 32.5 R cement is used for clay stabilization. The water used is that of the distribution network.

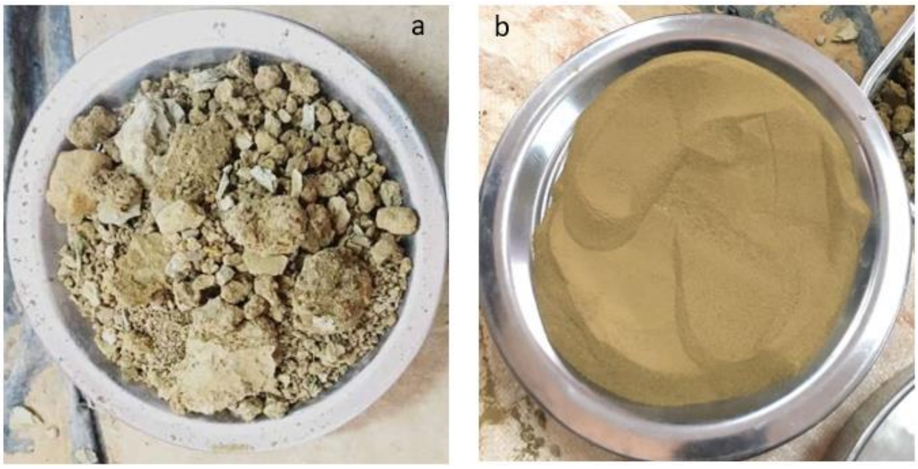

Figure 3: Thicky clay (a: raw clay, b: crushed and sifted clay)

Samples preparation

There are different methods of formulating plant-based concretes. In our study, binder was first prepared by manually mixing only clay or clay and cement with the required amount of water for 3 min until a homogeneous mixture was obtained. Fibers were then added and the whole was mixed again for 4 min before being placed in molds. Mass composition and water/binder ratio of different samples are shown in Table 1.

Table 1: Mass content of Samples (%)

Sample	Typha	Clay	Cement	W/B
F 200 0C	11	89	0	0.7
F 200 1C	11	79	10	0.69
F 200 2C	11	69	20	0.68
F 200 3C	11	59	30	0.67

Mechanical test

Mechanical characterization consists of the determination of compressive strength of Typha-clay composites. The specimens for mechanical characterization are shown in Figure 4. Compressive strength tests were determined by hydraulic press sensitive to fiber concrete after 28 days of maturation. The compressive strength is then determined by equation (1).

$$R_C = \frac{f}{S} \quad (1)$$


Figure 4: Sample for mechanical test

Thermal Conductivity Measurement

Different methods exist for determining the thermophysical properties of materials. In general, they are classified into two main families that the transient methods like the asymmetric hot plane method, the hot wire method, the flash method etc. and the permanent regime methods like the box method, the guarded hot plate method, the radial flow method etc. In our study, thermal conductivity measurements were conducted using box method due to its availability. The use of this method is simple but its implementation takes several hours or even a day. Figure 5 presents sample for thermal measurement. The principle of this method consists to produce a permanent unidirectional heat flow through the sample to be tested. The dispositive of this method are shown in Figure 6. The measurements are made on prismatic samples of dimension 27 cm × 27 cm × 5 cm and under real conditions of use of the material.

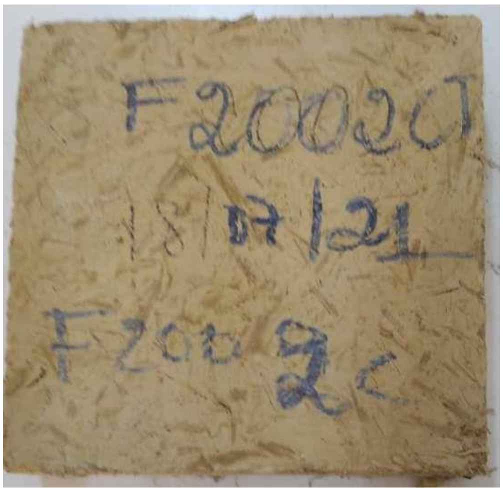

Figure 5: Sample for thermal test

The sample is placed between a hot and a cold environment with a constant heat flow whose energy emission is regulated by a rheostat. The lower enclosure is cooled by a heat exchanger in which circulates a constant temperature fluid (glycol water, ethanol). The temperature measurements are carried out after the permanent regime has been reached. The value of the thermal conductivity is deduced from equation (2) [15], [16].

$$\lambda = \frac{e}{S(T_c - T_f)}\left[\frac{V^2}{R} - C(T_b - T_a)\right] \quad (2)$$

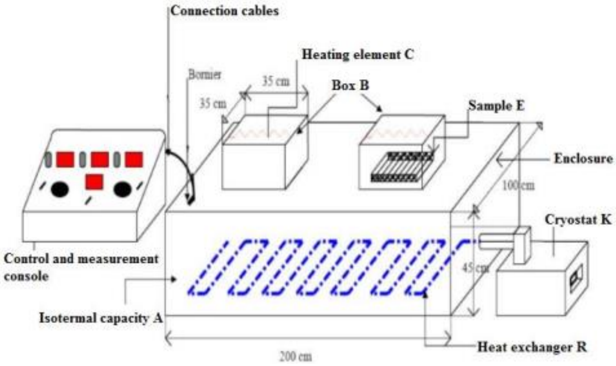

Figure 6: Schematic presentation of the device of box method [15]

Results & Discussion

Mechanical results

The mechanical results concern the compressive strength. The evolution of this one according to the percentage of cement is presented on Figure 7. It is observed that the compressive strength increases according to the percentage of cement. Addition of cement thus makes it possible to improve the mechanical properties of the clay-Typha composites. Compressive strength values range from 0.14 to 0.71 MPa. These results are comparable to those of Typha clay concretes whose compressive strength ranges from 0.279 to 0.796 MPa [3] and to those of hemp-lime concretes whose compressive strength ranges from 0.15 to 0.83 MPa [17].

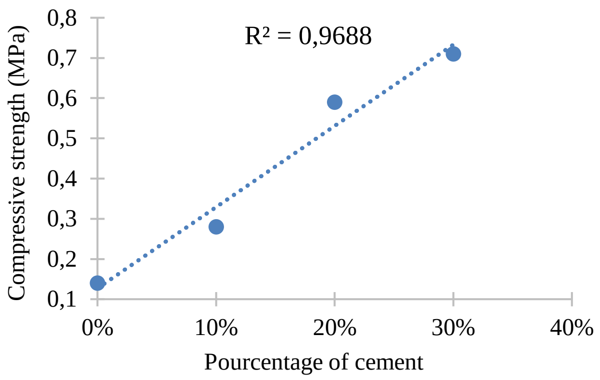

Figure 7: Compressive resistance according to cement percentage

Thermal Results

The average results of measuring the different samples thermal conductivity are summarizes in Table 2. Results show that all measured samples have the same thermal conductivity. Indeed, addition of cement does not influence the thermal properties of the composites. This phenomenon is due to the fact clay paste and cement paste have similar thermal conductivities which are 0.65 W/m. k [4] for the clay and 0.53 W/m. k [18] for the cement. Thermally these two materials can be classified in the same family.

Table 2: Thermal results

Cement (%)	0	10	20	30
λ (W/m. K)	0.18	0.16	0.17	0.19

Conclusion

This experimental study focused on the mechanical and thermal characterization of Typha and clay-based materials for use in sustainable construction. The impact of adding cement as a stabilizer of the clay was studied. From the point of view of mechanical performance, the addition of cement has a positive impact on the materials. However, it does not affect the thermal properties of the materials. The addition of cement in the materials has therefore improved the mechanical performance of Typha clay composites while maintaining its thermal properties.

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