

Hygrothermal Properties of a Composite Based on Clay Soils and Diatomite

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Abstract

The purpose of this paper is to make a contribution to the use of diatomite as a mineral additive in the composition of compressed earth blocks. The aim is to study the influence of diatomite on the hygrothermal behaviour of composites based on clay soils. For this reason, two clay soils with different physicochemical and mineralogical compositions were incorporated with diatomite at percentages ranging from 5% to 50% with a step of 5 to produce compressed earth blocks. After assessing the hydric and thermal characteristics of the composites, it was found that the incorporation of diatomite into the clay matrix favours the absorption of water by capillary action for all the composites. The diatomite-amended blocks subjected to the rain erosion test were less eroded than the unamended blocks. In addition, BYD composites were found to be more resistant than BTD composites, due to the high percentage of clay in T soil. The thermal conductivity of the latter decreases respectively from 0.72 to 0.29 W/m·K for BTD composites and from 0.52 to 0.21 W/m·K for BYD composites. This reduction proves the thermal insulating properties of diatomite. Despite the high capillary absorption capacity of these composites, they have good thermal properties, enabling them to be used in the construction of buildings for improved indoor thermal comfort.

Keywords

Clay Soil, Diatomite, Capillary Absorption, Erodibility and Thermal Conductivity

1. Introduction

One of the major concerns of materials researchers today is to reduce the ther-

mal loads of buildings. Reducing this load is one of the solutions for minimising energy consumption in buildings and combating the effects of climate change. There is an intrinsic relationship between the energy consumption of materials and the environmental impact of a building's life cycle [1]. However, to reduce energy consumption in homes, it is essential to promote alternative methods from the construction stage onwards, through the use of materials that provide thermal comfort and reduce conventional energy requirements. Raw earth is one of the building materials recognised for its high thermal inertia and abundance, but it suffers from problems of sensitivity to water, systematic cracking and hygrothermal performance measurement. To remedy these problems, several types of soil stabilisation have been used to improve the characteristics of the soil. In addition, measuring its hygrothermal performance remains another key issue, when stabilisers such as cement, lime, ash, fibres, etc. have been incorporated into the clay soil [2]-[5]. In this study, diatomite is used as an additive in clay matrices because of its interesting structure and thermal properties [6]. The aim of this research is to develop and determine the hygrothermal behaviour of composites made from two clay soils and diatomite. Particular emphasis will be placed on the capacity of these composites to absorb water by capillary action, resistance to erosion, thermal conductivity and thermal effusivity as a function of diatomite percentages. These parameters are particularly useful for characterising a material from a hygrothermal point of view.

2. Materials and Methods

2.1. Clay Soil and Diatomite Samples

The clay soil samples used were the subject of a preliminary geotechnical, physicochemical and mineralogical characterisation study, the results of which were presented in our previous work [7]. According to the conclusion, the two soils studied are different in nature. Soil T is very plastic and characterised as a clay-loam soil, whereas soil Y is less plastic and classified as a sandy-clay-loam soil.

The diatomite used comes from the Motto (Oquadis) quarry in Kanem province in northern Chad. It is used as an additive in the matrix of clay soils to produce compressed earth blocks. From the results of the chemical and mineralogical analyses, the diatomite sampled contains a significant quantity of silica (74.53%) and more than half of quartz (51.57%).

2.2. Preparation of Block Samples

For this study, specimens of dimensions ($4 \times 5 \times 8 \text{ cm}^3$) manufactured using two clay soils with or without diatomite incorporated in proportions ranging from 5 to 50% were produced. The BTD and BYD formulations of soil T and soil Y plus diatomite respectively were produced with corresponding water contents. The influence of diatomite and water content on the hygrothermal properties of block specimens remains to be determined.

2.3. Water Absorption by Capillarity

The purpose of the water absorption test is to determine the quantity of water absorbed by the immersed material over a period of time t using relationship (1). The test was carried out on $4 \times 4 \times 16 \text{ cm}^3$ composite materials in accordance with ASTM C 20 [8]. In direct contact with water, the composite material sample absorbs water by capillary action. The test described by the AFPC-AFREM protocol consists of measuring the progression of the mass of the test tube placed in a container with a water level 6 mm above the underside of the test tube (Figure 1). Variations in mass were monitored by successive weighings over a measurement period of 1, 5, 10, 15, 30, 50 and 60 minutes. The test tubes were partially covered with filter paper to prevent premature degradation during the weighing periods.



Figure 1. Capillary absorption test of composite specimens.

The absorption coefficient is determined by the following relationship.

$$A = \frac{m_i - m_s}{s \cdot \sqrt{t}} \quad (1)$$

where, A : the absorption coefficient in $(\text{kg}/\text{m}^2 \cdot \text{s}^{1/2})$, m_i : the mass of block soaked in water for a time t in kilograms (kg), m_s : the mass of dried block in kilograms (kg), s : the lower surface of the block base in metres (m) and t : the absorption time in seconds (s).

2.4. Rain Erosion Resistance Test

Simulating rainfall on compressed earth blocks therefore also makes it possible to isolate the soil factor and observe its behaviour without confusing it with other environmental factors. This test consists of simulating the normalized artificial rainfall experienced by the face of the block specimens exposed to the rain [7]. It is carried out using a pump maintaining a constant pressure of 2 bars with a flow rate of 5 l/min for 15 minutes. The shower column is connected upstream of the pump, 50 cm above the support inclined at an angle of 30° to the vertical on which the bricks under test rest (Figure 2). The principle consists of drying the test specimens in the oven for 24 hours at a temperature of 105°C and weighing them before and after the test.



Figure 2. Test pieces in full erosion test and eroded test pieces.

The degree of degradation of the specimens subjected is determined using the formula below.

$$D(\%) = 100 \times \frac{m_1 - m_2}{m_1} \quad (2)$$

where: $D(\%)$ is the rate of degraded composite, m_1 is the mass of starting BTC and m_2 is the mass of degraded composite.

2.5. Methods Used to Determine Thermal Parameters

Thermal conductivity is the flow of heat through a material one metre thick thickness of one metre for a temperature difference of one Kelvin between the two surfaces. Thermal effusivity, on the other hand, represents the capacity of a material to exchange thermal energy with its environment. The thermal conductivity and thermal effusivity of composites are measured by the hot-wire method using a hot-wire and hot-plane conductivity meter (NEOTIM FP2C). The test involves measuring the coefficient of thermal conductivity and effusivity by placing a thermal shock probe between two samples of composites with their respective good surface conditions (Figure 3). This probe is equipped with a thermocouple linked to a source that generates heat in the material and a thermogram that measures the response of the material over time. This technique has the advantage of being fast and flexible in relation to the dimensions of the specimens, but remains sensitive to the quality of the surface in contact with them. The probe used has a coefficient of 1, the power of the source is 0.5 W and the duration of the measurement is approximately 60 seconds after stabilisation.

3. Results and Discussion

Figure 4 shows the variations in absorption of blocks from two mixtures as a function of diatomite percentages. Samples without the addition of diatomite have an average absorption coefficient of 49.01%, whereas other samples amended with different levels of diatomite have an average water absorption coefficient of 60.13%, *i.e.* an increase of 11.12%. With regard to BYD composites, the absorption coefficients are distributed as follows: 50.11% of mortar without diatomite and 56.29% of composites, *i.e.* an increase in absorption coefficients of

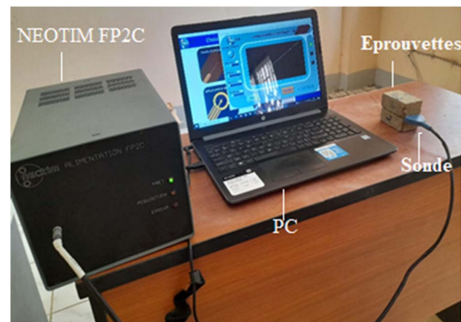


Figure 3. Devices for measuring the thermal conductivity and effusivity of blocks.

around 6.18%. Absorption coefficients increase as the percentage of diatomite in the clay matrix increases. This capillary increase in composites depends in particular on the open porosity of the material [9]. Diatomite incorporated into the clay matrix favours total porosity, these results are in agreement with the conclusion of [8] on compressed earth block CEB amended with 20% diatomite waste and of [10] [11] on CEB or adobes amended with plant fibres or aggregates and ash. These latter conclusions are contrary to those of [12] [13], using pumice, fly ash and peanut shell powders. Certain values of the absorption coefficients show that the addition of a few levels of diatomite cannot have a beneficial effect on the hydrous behaviour of composites.

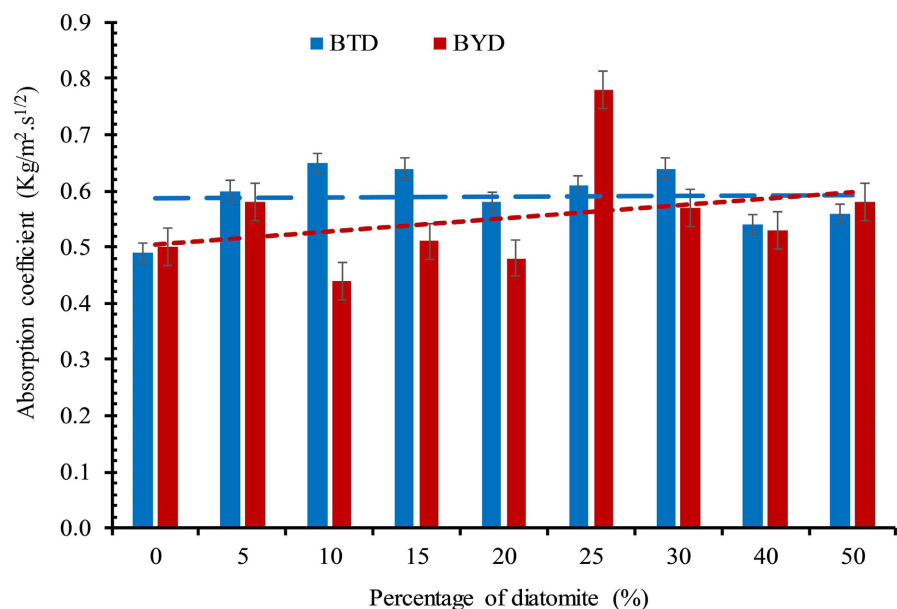


Figure 4. Capillary water absorption coefficients of BTD and BYD composites.

The results of the mass loss of the composites after the rain erosion test presented in **Figure 5** show that the two composites BTD and BYD have different erosion resistances. The weight loss of BTD composites increases with the percentage of diatomite (37.12% to 53.92%) to around 10.49% compared to refer-

ence mortars. On the other hand, the loss of mass decreased with the diatomite content (23.41% to 14.79%) compared to the untreated specimens. A reduction in mass of around 17.72%. Compared with BTD composites, BYD composites have good resistance to rain erosion, but even so, the mass loss values for both composites are higher than the maximum permitted [14]. The mass loss of the BYD₅₀ composite is close to the recommended 10% for building bricks.

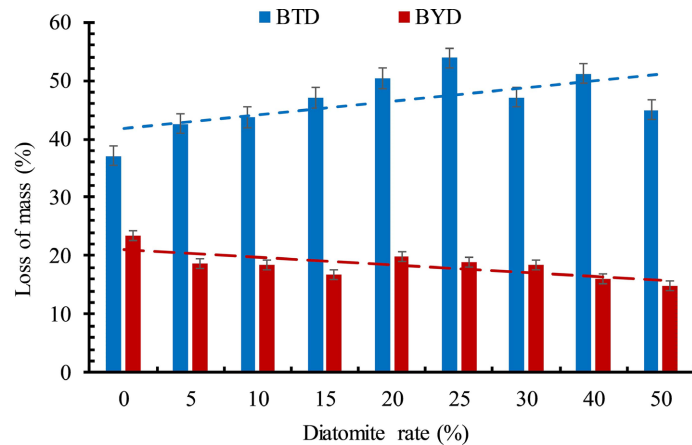


Figure 5. Mass losses after the BTC rain erosion test.

The various thermal conductivity results are shown in **Figure 6**. The curves obtained show variations in thermal conductivity as a function of the percentage of diatomite in the BTD and BYD composites. Adding diatomite content lowers the thermal conductivity values of BTD composites from 0.72 to 0.29 W/m·K and BYD composites from 0.52 to 0.21 W/m·K respectively.

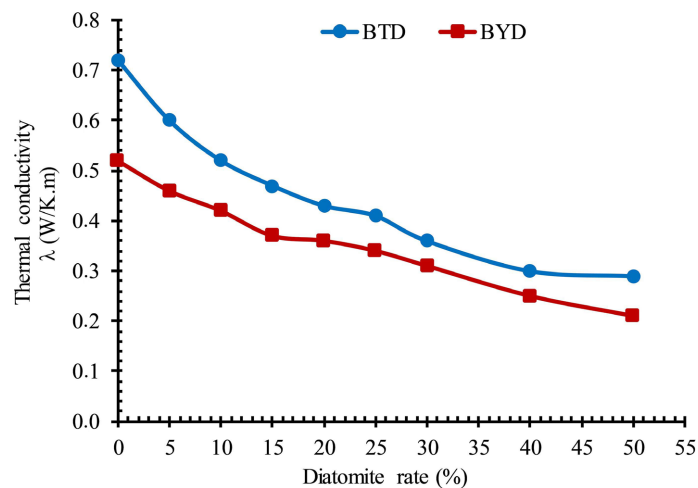


Figure 6. Variation in thermal conductivity as a function of diatomite content.

The drop in thermal conductivity values can be explained by the increase in pores due to the intrinsic characteristics of diatomite and voids due to the evap-

oration of water in the specimens after drying. According to [15], steady-state heat transfer is by conduction, so pores represent gaps for heat flow transfer. According to the results obtained, the thermal conductivity values measured decrease considerably as the diatomite content increases. This phenomenon is consistent with the intrinsic properties of diatomite, which is a thermal insulator. However, for BTD and BYD composites, the thermal conductivities decrease by an average of around 40% for the different formulations, compared with specimens without the addition of diatomite. These results are better than those reported by [16], using diatomite in the clay matrix, but in line with those reported by [9] [17]. The thermal conductivity results of this work corroborate the recommended values (0.5 to 1.7 W/m·K) for stabilised or unstabilised CEB [8] [17] [18]. The low thermal conductivity of these materials helps to reduce heat conduction from the outside to the inside, and regulates the temperature inside buildings. This provides good thermal comfort inside buildings, while reducing electrical energy costs.

The influence of curing time on thermal conductivities shown in **Figure 7** and **Figure 8** respectively is not noticeable in either composite. This phenomenon can be interpreted by the departure of water, leaving voids and thus intrinsic diatomite characteristics in the mixtures. The results of this work corroborate the conclusions of [19] [20] on CEB and [13] on peanut-amended adobes. As the specimens age, the water in them evaporates, leaving voids.

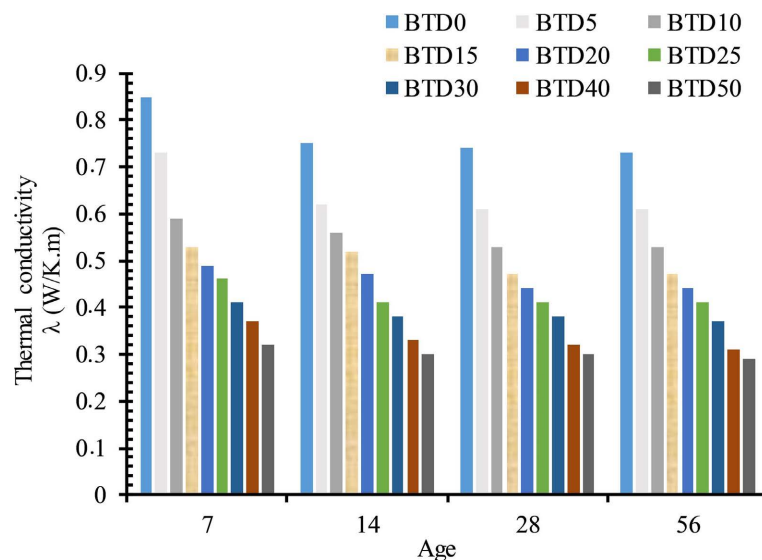


Figure 7. Influence of age on the thermal conductivity of BTD composites.

The thermal effusivity values of the composites are shown in **Figure 9**. The variation in the thermal effusivity curves of composites is similar to that of thermal conductivity. A decrease in this property with increasing percentages of diatomite is also observed in all cases. These results corroborate the conclusions of work by authors [16] [21] using diatomite.

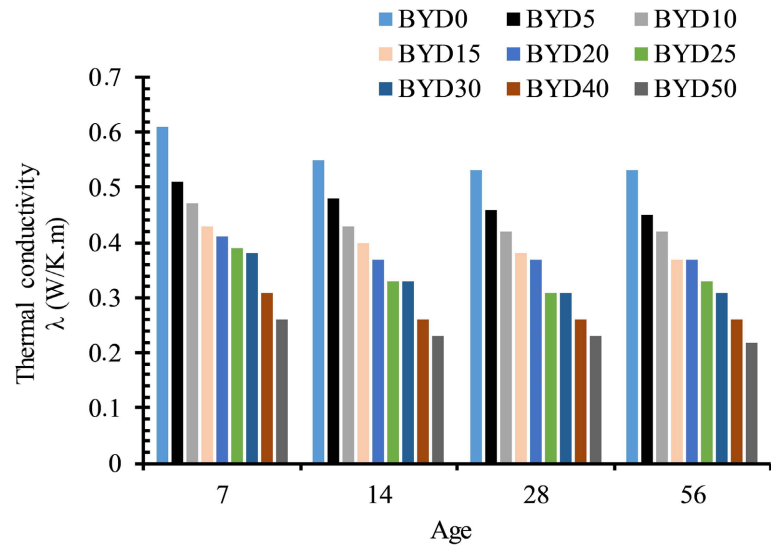


Figure 8. Influence of age on the thermal conductivity of BYD composites.

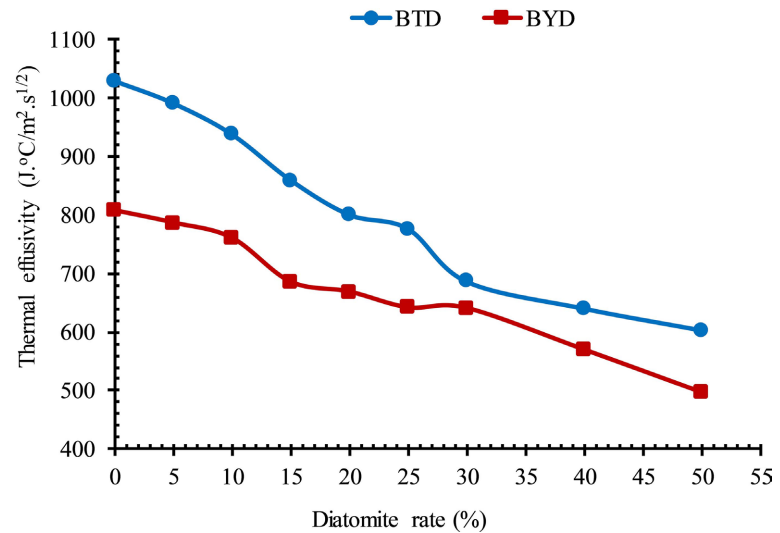


Figure 9. Thermal effusivity as a function of diatomite content.

Figure 10 shows the thermal conductivities as a function of composite density. Thermal conductivity decreases with density as the diatomite content increases, leading to a reduction in thermal properties. For all composites (BTD and BYD), when thermal conductivity values increase with specimen density.

The various thermal conductivity results in this work are compared with the mechanical and thermal requirements of construction materials such as structural and insulating concretes in accordance with the RILEM recommendation [22]. According to the RILEM functional classification, the properties of composites are comparable to those of lightweight aggregate concretes as structural and thermal insulation materials [22]. The determination of crucial parameters such as the density, mechanical strength and thermal resistance of materials in the field of building construction makes it possible to choose the optimum point and

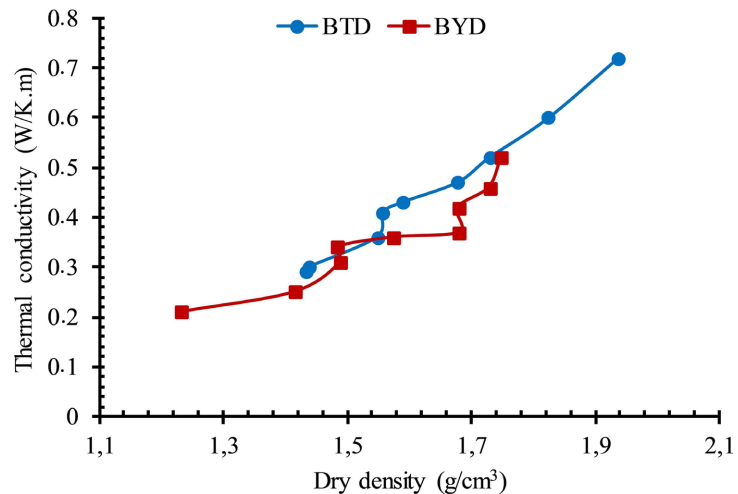


Figure 10. Thermal conductivity as a function of density of BTD composites.

type of materials used in construction. A sufficient knowledge of these three important parameters for composite use is therefore necessary to make optimum use of the qualities of strength, lightness and insulation.

4. Conclusions

The hydric and thermal behaviour of various composites based on clayey soils and diatomite presented and discussed in this article gave satisfactory results, particularly with regard to thermal properties. We note that the absorption of water by capillary action of the composites increases as the percentage of diatomite increases. This absorption is much more noticeable in BYD composites than in BTD composites, but is perfectly acceptable for construction purposes. The rain erosion test showed divergent results between BTD and BYD composites. The severe deterioration of BTD blocks by water is due to the high quantity of the active element (clay) in the T soil. They are qualified as unsuitable for the construction of buildings in regions with high rainfall. Thermal parameters generally decrease considerably as the diatomite content increases in clay matrices. However, the incorporation of diatomite reduces thermal conductivity values by more than 40%. In fact, for the different levels of diatomite used in clay soils, the measurements of the thermal parameters of the composites are very close to the recommended thermal requirements for construction materials. These composites can be used as new bio-composite materials to reduce energy loads in buildings.

In the future, the authors plan to carry out a study of the durability and aging of these composites by simulation, in order to predict the service life and maintenance requirements of the proposed materials.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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