World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Thermal and acoustic conductivity of a composite material based on rice straw

Agré Séraphin DJOMO [1, *], Abé Parfait SOMBO [1], Lydie Marcelle THIEBLESSON [1] and Conand Honoré KOUAKOU [2]

[1] *Department of Earth Sciences, Jean Lorougnon Guédé University of Daloa, Faculty of Environment, BP 150 Daloa, Ivory Coast.*

[2] *Félix Houphouët-Boigny University, UFR STRM, Laboratory of Geomaterials and Housing Technology, 22 BP 582 Abidjan 22, Côte d'Ivoire.*

World Journal of Advanced Research and Reviews, 2026, 29(01), 574-582

Publication history: Received on 29 November 2025; revised on 06 January 2026; accepted on 09 January 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.0024

Abstract

The objective of this study is to contribute to the development and promotion of a plant-based building material with a limited environmental impact and acceptable energy consumption. To this end, we manufactured a composite material (straw + plaster). A plaster coating was applied to the two opposite sides of the straw bale. Several tests were conducted to improve thermal comfort, including the material's thermal diffusivity, moisture conductivity, and acoustic conductivity. The results obtained during this study are presented in relation to the methodology used. The moisture content of the material remained constant due to the presence of a NaCl solution, which controlled the humidity. The clay-coated straw bale regulates the internal temperature in a climatic environment subject to temperature variations, thus providing it with significant thermal inertia. Acoustic insulation aims to limit the transmission of sound between the two sides of the material. The R value is between 45 and 53.1 dB in the device containing the material, it is a good acoustic insulator.

Keywords: Composite material; Coating; Acoustic insulation; Water conductivity

1. Introduction

The building sector must work towards a transformation of its construction practices to improve the energy performance of new and existing buildings. It must also offer innovative materials that meet the new requirements of users and legislation in terms of environmental and health impact, and comfort (Magniont, 2010). Residential buildings account for approximately 40% of global energy consumption (Mounir et al., 2014; Bahria et al., 2016). Residential buildings are responsible for a significant portion of greenhouse gas emissions (Abderraouf, 2016). The increase in greenhouse gas (GHG) emissions is the main source of global warming observed in recent years. Greenhouse gas emissions are largely due to energy production based on fossil fuels such as oil. Furthermore, one of the major concerns in tropical countries like Côte d'Ivoire is the significant overheating of homes due to intense sunlight. To address this, there is widespread use of air circulation devices, which leads to high energy consumption and health problems. Given the cost of energy in these countries, it is necessary to find less energy-intensive and more environmentally friendly construction methods (Kouadio, 2010). The use of fibers to create composite or laminated materials is becoming increasingly widespread. These composites are used in various sectors: the transportation industry (automotive, aerospace, rail), the military, and the building and construction industry. Fibres have the advantage of contributing to the development of lightweight products with high mechanical strength, low thermal and acoustic conductivity and high energy absorption capacity (Banthia et al., 1994). In recent years, natural resources have been steadily dwindling, and the construction sector is a major contributing factor. These plant fibers are found in all countries, generally in large quantities, or they often constitute agricultural waste that must be disposed of. Straw, long considered a second-

* Corresponding author: Agré Séraphin DJOMO

category waste, has tended to be revalued in recent years. It is most often left on the fields after harvest to be burned or buried over the winter. This straw has particular characteristics due to its silica content and its abrasive nature (low potential for degradation and wear of equipment). Indeed, the energy crisis compels us to find new solutions. In this regard, straw seems promising. Straw bale construction offers good thermal insulation. It fully contributes to the well-being of the inhabitants who live within its walls. However, in what forms can this product be used, as a building material, in today's constructions to improve the thermal properties of housing in Ivory Coast? Thus, the present study aims to contribute to the development and promotion of a plant-based building material with limited environmental impact and acceptable energy performance.

2. Material and Methods

2.1. Material

2.1.1. Raw Material

The raw materials used for this work consist of rice straw (PDR) harvested in the vicinity of the city of Daloa (Central-West of Côte d'Ivoire). For the rice straw, dried rice stalks with their leaves removed are used. The rice straw thus obtained is stored in a room at a temperature of 25°C. The clay used is extracted in the commune of Anyama (Southeast Ivory Coast).

Figure 1 Rice straw

Figure 2 Clay

2.1.2. Technical Equipment

In the execution of the study, in addition to the conventional equipment used (an oven for drying the different samples at a given temperature; a balance, a 250 µm sieve, a sieve column, a beaker, two test tubes, a sodium hexametaphosphate (HMP) solution, a densimeter, a thermometer) a homemade press for making straw bales (Figure 3-a) and a thermal chamber made with polystyrene (Figure 3-b) were made.

a) A press; b) A thermal chamber

Figure 3 Technical equipment

2.2. Methods

2.2.1. Formulation of rice straw-based composite materials

Coating preparation

The shaping of the plaster began with the preparation of the clay. This operation consisted of crushing the clay in order to obtain a pulverized material. The clay was then sieved through a 1 mm mesh to remove impurities. The fraction passing through the 1 mm sieve was used for the preparation of the mortar. The preparation of the mortar was carried out in two stages. The clay and cement were dry-mixed in a mixing bowl for 5 minutes. Water was then gradually added to the previous mixture, and the whole was mixed for 4 minutes until a homogeneous paste was obtained. For the formulation of the mortar, 92 % by mass of clay and 8 % by mass of cement were used, with a water content of 60 %. These proportions were chosen because, according to Kouakou (2005), 8 % cement is required for clay–cement mixtures to be suitable for construction purposes.

Manufacturing process of rice straw bales

The rice straw stored in the laboratory is first sun-dried for three days. Subsequently, a constant volume of straw is placed into the press mold after the tying ropes have been positioned. The press lever is then operated to compact the rice straw. While maintaining the lever in the compressed position, the ropes are tied. Finally, the lever is released and the bale is removed from the press mold. Figure 4 shows the rice straw bales.

Figure 4 Rice straw bales

Manufacturing process of the composite material (Straw + Plaster)

For the preparation of the composite material, the plaster is applied to both opposite faces of the straw bale. To this end, the previously prepared plaster is poured into a mold and vibrated on a vibrating table for 2 minutes. Subsequently, one face of the straw bale is immersed in the mold containing the mortar and left to dry for 3 days. The material is then demolded, and the same procedure is repeated on the opposite face. The Plaster–Straw–Plaster composite is left to dry for 28 days before carrying out the various tests.

2.2.2. Methods for characterizing the composite material (plaster–straw–plaster)

This section presents the tests conducted on the composite material by measuring parameters such as humidity and temperature.

Thermal diffusivity

A body can transfer heat from one face to another. This heat transfer occurs between two faces with different temperatures (Michot, 2008). Heat flows from the hotter face to the cooler face until thermal equilibrium is reached. Heat transfer takes place through three modes: conduction, convection, and radiation. Thermal diffusivity expresses the ability of a material to transmit heat. The longer heat takes to pass through a material, the lower its thermal diffusivity. It therefore quantifies the capacity of a material to conduct heat more or less rapidly (Mnasri, 2016). For the measurement of thermal diffusivity, the material is placed between two chambers (Figure 5).

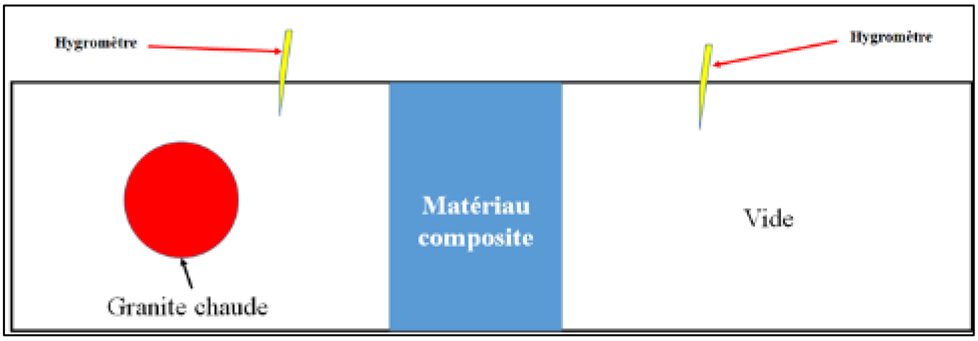

Figure 5 Temperature measurement device

In one of the chambers, a heating system is installed to raise the temperature. Temperature sensors are placed in both chambers, and temperature measurements are recorded at 1, 2, 3, and 4 hours.

Hygroscopic conductivity

The hygroscopic conductivity curve reflects the ability of a material to transmit moisture (or water vapor). It allows certain materials to regulate humidity in an indoor environment. To determine the hygroscopic conductivity of the composites, the specimens were used to divide a chamber into two compartments (Figure 6). Subsequently, after different exposure times in the chamber, humidity and temperature were measured. Measurements were taken after 1 hour, 2 hours, 3 hours, 4 hours, and 24 hours. Three humidity levels were created using different solutions:

- Ambient humidity (no solution);
- Humidity between 90 and 100% (using water);
- Humidity of 75% (using a nacl solution containing crystals).

The solution was introduced into one of the compartments (Figure 6). For each measurement, a hygrometer was used. The probe was inserted into each compartment, and the reading was taken 10 minutes later. The objective was to determine the time at which a variation in humidity is observed in compartment 2 of the chamber.

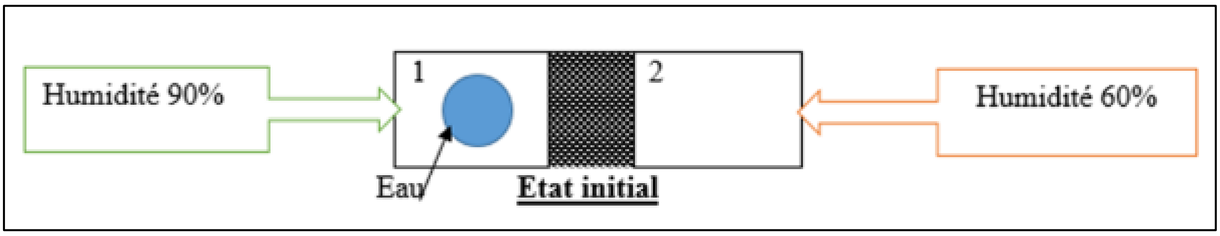

Figure 6 Experimental setup for hygroscopic conductivity measurement

Acoustic Conductivity

Sound consists of a superposition of signals with different frequencies. The propagation of sound is disturbed when obstacles are in its path. However, some materials have the ability to transmit sound from one side to the other. In such cases, they cannot be used as partitions or to separate two adjacent rooms. To assess the ability of earth–straw sandwich composites to transmit sound, their acoustic conductivity was measured. To determine the acoustic conductivity of the composites, they were used to separate two chambers (Figure 7). In Chamber 1, a sound with a known intensity (60 dB) was produced. In Chamber 2, a sound level meter (Figure 8) was placed to measure the sound level in that chamber.

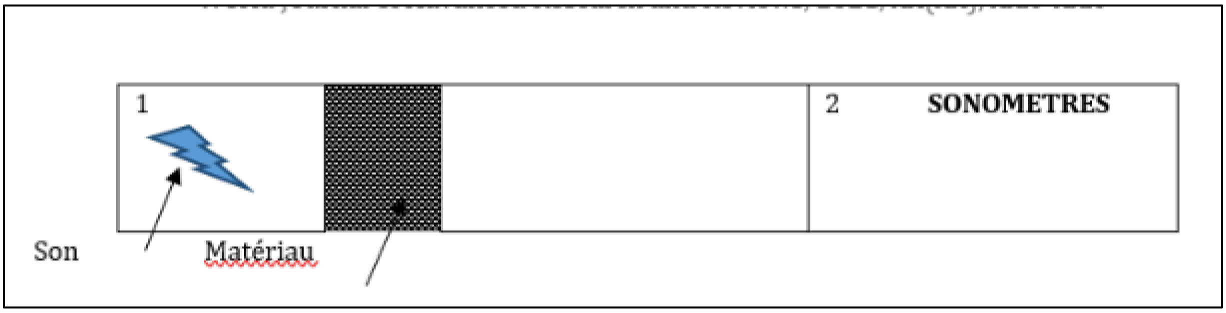

Figure 7 Setup for the Acoustic Conductivity Test

Figure 8 Sound Level Meter

3. Results

3.1. Formulation of the Rice Straw Bale

Well-dried straw at the time of cereal harvesting, baling, and during storage ensures the durability and strength of the bale wall. The moisture content of the bale at the time of purchase and installation should not exceed 15%. The history of the bale is very important. The straw must not have been in prolonged contact with water. A gray or black bale, even if dry, will have lower strength if it is exposed to water again. The most durable straw consists of whole stems and contains no grain or grain residues. A bale of straw prepared in this way has a mass of 320 g. The physical characteristics of the straw bale are given in Table 1.

Table 1 Physical Characteristics of the Straw Bale

Characteristics	Length (cm)	Width (cm)	Thickness (cm)	Mass (g)
Straw bale	20	15	17	320

3.2. Formulation of the Composite Material (Straw + Plaster)

Once the plaster is applied directly to the surfaces of the bales, the finished wall becomes a hybrid of straw and plaster. The characteristics of the composite material are: length, 20 cm; width, 15 cm; and thickness, 21 cm.

- Characterization of the Rice Straw-Based Composite Material
- Thermal Diffusivity

The orange curve in Figure 9 shows the moisture content in the first part of the chamber where the heating system is installed. A decrease in moisture is observed, from an initial 64% down to 41%, then it gradually increases to reach 73% after 50 minutes and remains constant for the rest of the time, as the pores on the surface in contact with the heating system have reached their saturation level. In building materials, moisture can exist within the pores in two thermodynamic states: liquid or water vapor. The movement of water vapor in a porous medium generally depends on the pore size. Indeed, the larger the pores, the easier the circulation. The blue curve, on the other hand, highlights the moisture content in the other part of the chamber. A gradual increase in moisture is observed, reaching a peak of 84% after 50 minutes. Figure 9 shows the variation of moisture over time.

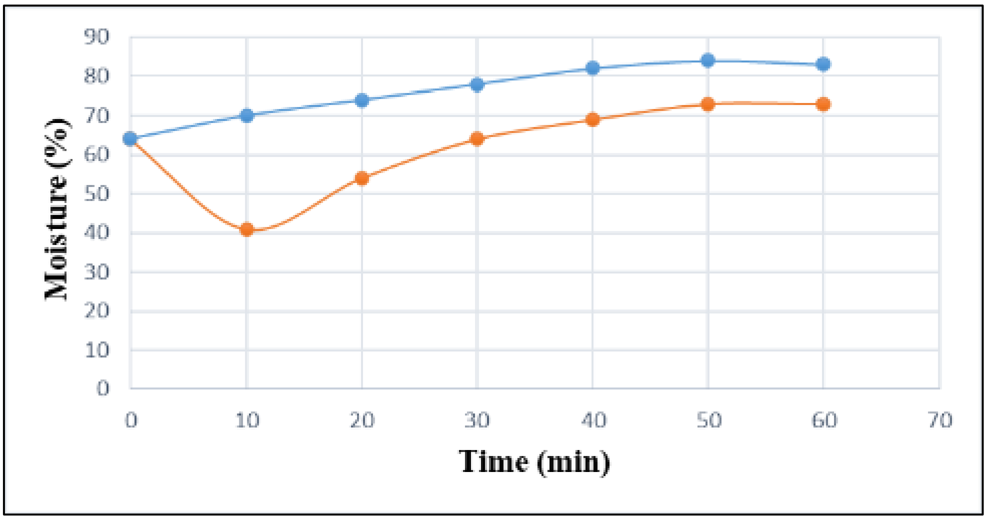

Figure 9 Variation of Moisture Over Time During Heat Transfer

The curves in Figure 10 show the variation of temperature over time. The temperature rises, reaching a peak of 36.3 °C in the first part of the chamber where the heating system is installed. It then gradually decreases until stabilizing throughout the process, while the temperature in the other part of the chamber remains constant regardless of time. In porous media, the dominant mode of heat transfer is conduction, which is often coupled with phase change due to the continuous presence of water in the material. Thus, the heat flux transfer results in a variation of the enthalpy of the material considered. The sample placed to divide the chamber into two parts acts as a good thermal insulator because it does not transfer the heat from the part containing the heating system to the other part of the chamber. In the case of a building, the surface in contact with the heating system represents the exterior face, which is always exposed to the outside environment, while the other face is considered the interior face of the building, ensuring the comfort of the occupants.

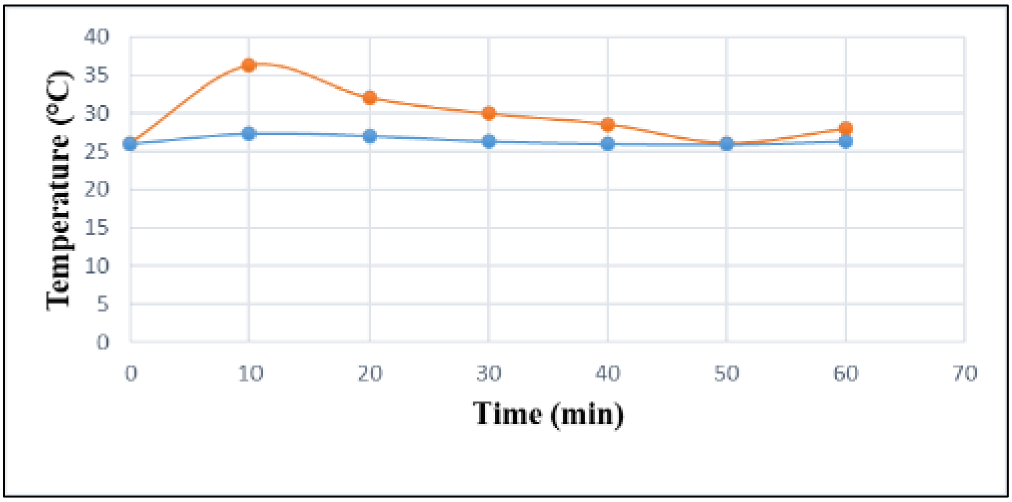

Figure 10 Variation of Temperature Over Time During Heat Transfer

The hygrothermal performance of a wall is often expressed by its ability to provide air tightness and regulate indoor temperature. Indeed, a wall is more efficient and durable if it resists water infiltration and properly controls water vapor flow. This performance is closely related to the type and nature of the materials used in construction. Specifically, the concept of hygrothermics in building materials refers to the evolution of temperature and ambient air moisture within an indoor space. Furthermore, this hygrothermal behavior strongly depends on the intrinsic hygroscopic properties of the material.

3.2.1. Moisture Conductivity

Figure 11 presents all the curves of the measured parameters. It provides an overall view of the variation in moisture within the chamber at each given time and highlights the differences observed. At the initial state, moisture ranges from 74% to 89% and reaches its peak after 1 hour, while at the final state, moisture ranges from 74% to 93% and reaches its peak after 2 hours. The higher moisture in the final state is due to the material absorbing moisture from the other part of the chamber.

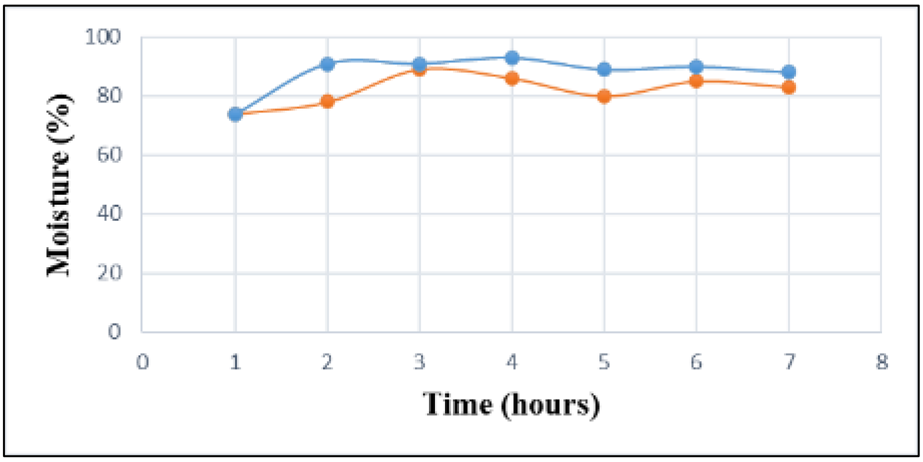

Figure 11 Variation of Moisture Over Time During Water Moisture Conductivity

The results of water vapor absorption are presented in Figure 12.

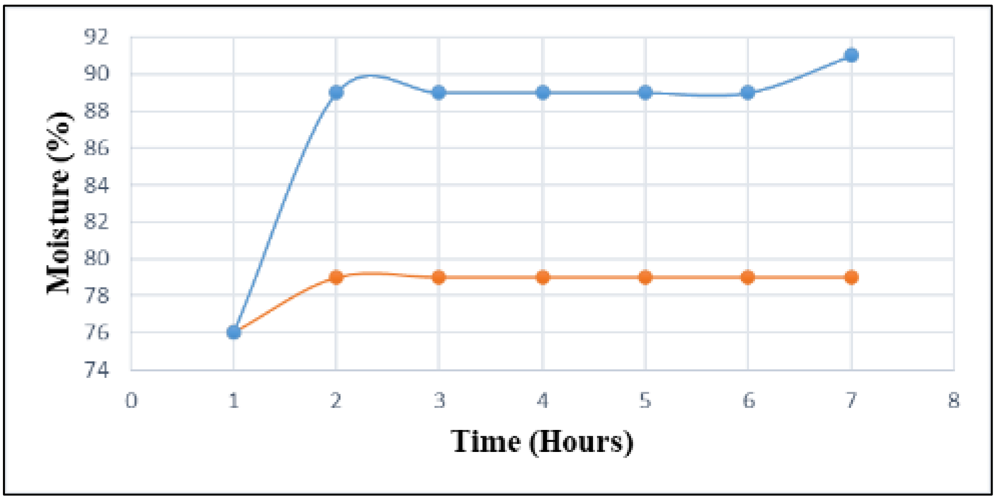

Figure 12 Variation of Moisture Over Time During NaCl Moisture Conductivity

This figure shows that moisture varies over time and presents two states separated by the material: the initial state and the final state. In the initial state, moisture does not vary and remains constant. This constant is due to the presence of the NaCl solution, which controls the humidity in this part, whereas in the final state, moisture first increases, then decreases, and eventually stabilizes over a long period. When measurements were taken the following day, an increase in moisture was observed, indicating absorption of water vapor from the other part of the chamber.

3.2.2. Acoustic Conductivity

The results show that the sound reduction value RRR is 35 dB inside the room. The sound reduction value increases. It ranges from 48 to 56.8 dB when the sound is emitted outside the chamber and the sound level meter is placed inside. Then, when both the sound source and the meter are inside the chamber, the sound reduction value varies between 45 and 53.1 dB. Finally, when the sound is emitted from inside the chamber and the meter is placed outside, the value measured in the room ranges from 45 to 52.7 dB.

- R=35R = 35R=35 dB: everything is audible
- R=40R = 40R=40 dB: speech is difficult to understand
- R=45R = 45R=45 dB: loud conversations are barely intelligible
- R=50R = 50R=50 dB: conversation is inaudible

Since the value of RRR ranges from 45 to 53.1 dB in the setup containing the material, the material studied is a good acoustic insulator.

4. Discussion

The presence of a NaCl solution in the chamber helps maintain constant humidity, as the material does not allow the water vapor from the initial part of the setup to pass through. When the air in a room reaches the vicinity of a wall facing the outside, its temperature decreases. Initially, this cooling occurs at constant specific humidity, while the relative humidity of the air increases. If the cooling continues, the moist air reaches saturation and condensation occurs. This analysis is similar to that of Mnasri (2016), who reported that wood–cement composite—a heterogeneous material composed of a mixture of plant particles and mineral particles—offers good absorption and desorption of water content. According to the Nordtest classification, all composites are excellent moisture regulators, except for the one made of hemp shives. Composites based on corn cob residues exhibit the best moisture-regulating performance. In building materials, moisture can exist within the pores in two thermodynamic states: liquid or water vapor. The movement of water vapor in a porous medium generally depends on the pore size; the larger the pores, the easier the circulation. In porous media, the dominant mode of heat transfer is conduction, which is often coupled with phase change due to the continuous presence of water in the material. Consequently, heat flux transfer results in a variation of the material's enthalpy. Since straw bales are good thermal insulators, it is important to understand the influence of plaster in this matrix. For this purpose, samples were placed in a chamber to measure the thermal diffusivity of the composite material and to avoid temperature losses. The presence of voids slows down heat transmission.

When a sound is emitted, an acoustic wave propagates through the air until it reaches an obstacle. When this incident wave comes into contact with a material, two waves are generated: a reflected wave that propagates in the same medium as the incident wave, and a transmitted wave that passes through the material. Acoustic treatment is a process aimed at influencing either the transmitted wave or the reflected wave in order to improve the acoustics of a room. Acoustic insulation aims to limit the transmission of sound across a material. This insulation is generally achieved using high-density materials, as their inertia makes them more resistant to motion caused by acoustic waves.

5. Conclusion

This work allowed us to develop a new material based on agricultural waste (rice straw) and clay, aiming to reduce environmental pollution. To combat global warming, measures are being taken to limit environmental pollution, and thus earthen materials are making a comeback in construction. The use of plant fibers as construction materials is gaining increasing attention, as is the case with rice straw, which is the focus of our study. The formulation of the samples was carried out in three (3) phases: the production of straw bales, followed by the preparation of the plaster, and finally, the implementation of the composite material. Various tests were conducted on the composite material, including thermal diffusivity, moisture conductivity, and acoustic conductivity. The experimental results obtained in this study allow us to draw the following conclusions:

- The NaCl solution helps regulate the moisture content from one room to another.
- Straw bales coated with clay contribute to the regulation of indoor temperature in climates subject to temperature variations.

Acoustic insulation aims to limit the transmission of sound across a material. This insulation is generally achieved using high-density materials, as their inertia makes them less easily moved by acoustic waves; in this study, the sound reduction value RRR ranged from 45 to 52.7 dB. Straw bales are now recognized as insulating materials and suitable substrates for plaster, and a methodological framework has been established for their characterization and implementation for these uses. However, multiple international studies show that it is possible to go even further by using straw bales directly as load-bearing materials for constructing individual houses.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abderraouf A., Naima B. & Fouad G., (2016). Thermal conductivity and thermal degradation of cementitious mortars reinforced with doum and diss fibers. *Proceedings of the International Conference on Materials and Energy – ICOME*, 16: 635–639.

[2] Bahria S., El Ganaoui M., Amirat M., Hamidat A. & Ouhsaine L. (2016). A Dynamic simulation of the low-energy building using woodbased material. *Proceedings of the International Conference on Materials and Energy,* 16: 641–644.

[3] Banthia N., Moncef A., Chokri K. & Sheng J. (1994). Micro-fibre reinforced cement composite: uniaxial tensile response. *Canadian Journal of Civil Engineering*, 21(6): 999-1011.

[4] Kouadio, K.C. (2010). Development and Characterization of Cement-Stabilized Clay Blocks (CIMARG): Influence of the Addition of Water-Reducing Agents on the Physical and Mechanical Properties of the Blocks. PhD Thesis, Félix Houphouët-Boigny University (Abidjan, Côte d'Ivoire), 188 pp.

[5] Kouakou, C.H. (2005). Valorization of Clays in Côte d'Ivoire: Study of the Stabilization of Compressed and Cement-Stabilized Clay Blocks Using Hydraulic Binders. PhD Thesis, Félix Houphouët-Boigny University (Abidjan, Côte d'Ivoire), 186 pp.

[6] Magniont, C. (2010). Contribution to the Formulation and Characterization of a Construction Eco-Material Based on Agro-Resources. PhD Thesis, Toulouse III – Paul Sabatier University (Toulouse, France), 343 pp.

[7] Michot, A. (2008). Thermo-Physical Characteristics of Clay-Based Materials: Evolution with Heat Treatments up to 1400°C. PhD Thesis, University of Limoges (Limoges, France), 116 pp.

[8] Mnasri, F. (2016). Study of Heat and Mass Transfer in Complex Media: Application to Fibrous Media and Building Insulation. Composite Materials and Construction. PhD Thesis, University of Lorraine (Nancy, France), 141 pp.

[9] Mounir S., Maaloufa Y., Cherki A.B. & Khabbazi A. (2014). Review thermal properties of the composite material clay /granular cork. *Construction Building Material,* 5: 183-190.