GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Check for updates

# Formulation of rice-straw-based composite materials

Séraphin Agré DJOMO [1,*], Pierre Kouakou KOUASSI [2] and Ronald Sosthène Désiré Yapi ATTO [3]

[1] *Department of Earth Sciences, Jean Lorougnon Guédé University of Daloa, Faculty of Environment, P.O. Box 150 Daloa, Côte d'Ivoire*

[2] *Laboratory of Geographic Sciences, Civil Engineering and Geosciences (LASCIG3), Félix Houphouët-Boigny National Polytechnic Institute, P.O. Box 1093 Yamoussoukro, Côte d'Ivoire*

[3] *Department of Mines and Reservoirs, University of Man, Faculty of Geological and Mining Sciences, P.O. Box 20 Man, Côte d'Ivoire*

*ORCID ID Séraphin Agré DJOMO: https://orcid.org/0009-0006-0555-5955*

*ORCID ID Ronald Sosthène Désiré Yapi ATTO: https://orcid.org/0000-0002-3852-9554*

GSC Advanced Research and Reviews, 2025, 25(03), 146–152

Publication history: Received 26 October 2025; revised on 08 December 2025; accepted on 10 December 2025

Article DOI: https://doi.org/10.30574/gscarr.2025.25.3.0375

## Abstract

The objective of this study is to contribute to the development and enhancement of a plant-based construction material with a limited environmental impact and acceptable energy performance. To achieve this, we manufactured a composite material (Straw + Coating) by applying the coating on the two opposite faces of the straw bale. To assess the reliability of the new material, several tests were carried out to evaluate thermal comfort, such as thermal diffusivity, moisture conductivity, and acoustic conductivity. The results obtained show that the moisture level does not vary and remains constant due to the presence of a NaCl solution that controls humidity. The straw bale coated with clay regulates indoor temperature in a climatic environment subject to temperature variations, thus providing high thermal inertia. The acoustic insulation value R, ranging from 45 to 53.1 dB in the device containing the material, shows that this material is a good acoustic insulator. Straw bales are currently recognized as an insulation material and as a support for coatings, and a methodological framework has been established regarding their characterization and implementation for these uses. Based on the assumption of a "sandwich" wall behavior in which the "straw/coating" interface plays a key role, experimental and theoretical challenges have been highlighted, and research directions to overcome them have been presented.

**Keywords:** Composite Material; Rice Straw; Insulation; Clay; Straw Bale

## 1. Introduction

The energy consumption of residential buildings represents about 40% of global energy use (Mounir et al., 2014; Bahria et al., 2016). Residential buildings are responsible for a significant share of greenhouse gas emissions (Abderraouf, 2016). The increase in greenhouse gas (GHG) emissions is the main cause of the climate warming observed in recent years. The consequences for the environment are harmful (cyclones, ecosystem imbalance, rising sea levels, flooding, etc.). GHG emissions are largely due to energy production based on fossil resources such as oil. This is why the construction and operation of buildings have a major direct and indirect impact on the environment. Indeed, when considering the life cycle of commonly used materials, the carbon footprint of buildings and the consumption of non-renewable resources are substantial (Touré, 2018).

Moreover, one of the major concerns in tropical countries such as Côte d'Ivoire is the significant heating of homes caused by strong solar radiation. To remedy this situation, air-circulation devices are widely used, leading to high energy

* Corresponding author: Séraphin Agré DJOMO.

consumption and health issues. Given the cost of energy in these countries, it is necessary to find construction methods that are less energy-intensive and more environmentally friendly (Kouadio, 2010). Furthermore, some construction practices and architectural styles are poorly adapted to the local climate, and there is a lack of expertise in the use of local building materials (earth, wood, straw, stone, etc.). These local materials currently suffer from a depreciated image due to their supposed low durability and fragility—an impression that results from a lack of knowledge about their characteristics and the benefits of their use in construction.

The use of fibers today for the development of composite or laminated materials is becoming increasingly important. These composites are used in various fields: the transportation industry (automotive, aerospace, rail), the military sector, as well as in building and construction. Fibers offer the advantage of contributing to the creation of lightweight products with high mechanical strength, low thermal and acoustic conductivities, and high energy absorption capacity (Banthia et al., 1994). In recent years, natural resources have been steadily declining, and the construction sector contributes significantly to this depletion. Plant fibers are found in all countries, often in large quantities, and they are frequently considered agricultural waste that needs to be disposed of. Straw, long regarded as second-rate waste, has been gaining renewed interest in recent years. It is most often left on fields after harvest to be burned or buried during winter. This straw has specific characteristics due to its silica content and abrasive nature (low degradation potential and equipment wear). Indeed, energy-related challenges compel us to seek new solutions, and in this regard, straw appears promising. Straw-based construction offers good-quality thermal insulation and contributes significantly to the comfort of the occupants living within its walls. However, the question remains: in what form should this material be used as a construction material today to improve the thermal performance of housing in Côte d'Ivoire?

Thus, the aim of this article is to contribute to sustainable development and to enhance the use of a plant-based construction material with limited environmental impact and acceptable energy performance. Specifically, the goal is to produce a composite material made from rice straw.

## 2. Materials

The development of a composite material requires raw materials and a well-defined preparation methodology. The quality of the material depends both on the fabrication process and on the intrinsic properties of the raw materials that compose it. Determining this quality relies on a series of interdependent tests that establish the material's performance and build confidence between the material and its future users. Optimizing the material's properties necessarily requires proper characterization of the raw materials used. In this article, the preparation methodology of rice-straw-based insulating samples, the various tests performed on them, as well as those carried out on the raw materials, are presented.

### 2.1. Raw Materials

The raw materials used in this work consist of:

**Figure 1** Rice straw

**Figure 2** Clay powder

Rice straw (Figure 1), used in this study, is obtained after harvesting rice from a field in the locality of Daloa in the Center-West of Côte d'Ivoire. The dry rice stems are stripped of their leaves. The rice straw thus obtained is stored in a room at a temperature of 25 °C.

Clay (Figure 2), used in this work, was collected in the locality of Anyama (South-East of Côte d'Ivoire) (Akoua et al., 2016).In carrying out this study, in addition to the conventional equipment used, a sodium hexametaphosphate (HMP) solution, a densimeter, a thermometer, a handmade press for producing the straw bales, and a thermal chamber made of polystyrene were manufactured.

## 2.2. Methodology

### *2.2.1. Characterization of the Clay*

To determine the characteristics of the clay, particle-size analysis by sedimentation, Atterberg limits, the methylene blue test, and a chemical analysis were performed.

Sedimentation analysis is based on the principle that grains of different diameters settle at different velocities in a liquid at rest. It was carried out according to the AFNOR (1992) standard. A 50 g test sample of the fine fraction is taken. To this fine fraction, 125 ml of sodium hexametaphosphate (HMP) solution is added. The mixture is left to stand for at least 18 hours. It is then homogenized in a beaker for 10 minutes and poured into a 1 L graduated cylinder, which is filled up to 1 L with distilled water. Simultaneously, the thermometer is placed in the reference solution, and the densimeter is slowly immersed in the homogenized solution. The timer is then started. Readings are taken at 30 seconds, 1, 2, 5, 15, 30, 60, and 1440 minutes (24 hours). The results of these tests allow the construction of the particle-size distribution curve, which is used to determine the percentages of sand, silt, and clay, and to specify the texture of the sample. The Atterberg limits are determined according to the French AFNOR (1980) standard, using the Casagrande apparatus and the cup method. The objective is to determine the water content of the clay sampled in Anyama at its transition from the liquid state to the plastic state. This test is performed on the soil fraction whose particles are smaller than 0.40 mm.

The methylene blue test determines the nature and content of fine particles (clay). It also provides an estimate of the specific surface area of the clays, since the specific surface area of the particles in a soil provides a selective characterization of its clay content. The test uses the property of the methylene blue molecule to adsorb onto the surface of mineral particles. It is performed by successively adding doses of a methylene blue solution to an aqueous suspension of the material and checking the absorption of the colored solution using a spot test on filter paper to detect the presence of free dye. In practice, a known mass of fines (200 g) dispersed in distilled water is used, to which increasing doses of methylene blue are added. The methylene blue value is expressed as the amount of dye, in grams, consumed per 100 grams of fines. The chemical analysis of the samples was carried out by X-ray fluorescence using an EDXRF (Energy Dispersive X-Ray Fluorescence) spectrometer. X-ray fluorescence spectrometry (XRF) is an elemental analysis method based on a physical property of matter: X-ray fluorescence. The analysis of the resulting spectrum makes it possible to identify the elements present in a sample and determine their concentrations.

## 2.3. Formulation Methods of Rice-Straw-Based Composite Materials

### *2.3.1. Preparation of the Coating*

The preparation of the coating began with the processing of the clay. This operation consisted of crushing the clay to obtain a powder, then sieving it with a 1 mm mesh to remove impurities. The fraction passing through the 1 mm sieve was used to prepare the mortar, which was produced in two steps. The first step consisted of mixing clay and cement dry in a container for 5 minutes. The second step consisted of gradually adding water to the previous mixture. The entire mixture was stirred for 4 minutes until a visually homogeneous paste was obtained. The formulation used for the mortar consisted of 92% clay by mass and 8% cement by mass. These proportions were selected based on the work of Kouakou (2005), who indicates that 8% cement is required for clay–cement mixtures to be usable in construction. The amount of mixing water was set at 60% of the mass of the clay–cement mixture to obtain a fluid mortar.

### *2.3.2. Manufacturing Process of the Straw Bales*

The rice straw stored in the laboratory was first dried in the sun for 3 days. Then, a constant volume of this straw was placed inside the mold of the press after the tying cord had been positioned. The lever of the press was activated to compact the rice straw. While keeping the lever in its compressed position, the cords were tied. The lever was then released to remove the bale from the press mold (Figure 3).

**Figure 3** Rice straw bale

*2.3.3. Manufacturing Process of the Composite Material (Straw + Coating)*

To produce the composite material, the coating must be applied to the two opposite faces of the straw bale. To do so, the previously prepared coating is poured into a mold and vibrated on a vibrating table for 2 minutes. One face of the straw bale is then immersed in the mold containing the mortar and left to dry for 3 days. After demolding, the same operation is repeated on the opposite face. The "Coating–Straw–Coating" composite is then left to dry for 28 days before performing the different tests.

## 3. Results and Discussion

### 3.1. Particle-Size Distribution of Anyama Clay

The results of the particle-size analysis are presented in Figure 4.

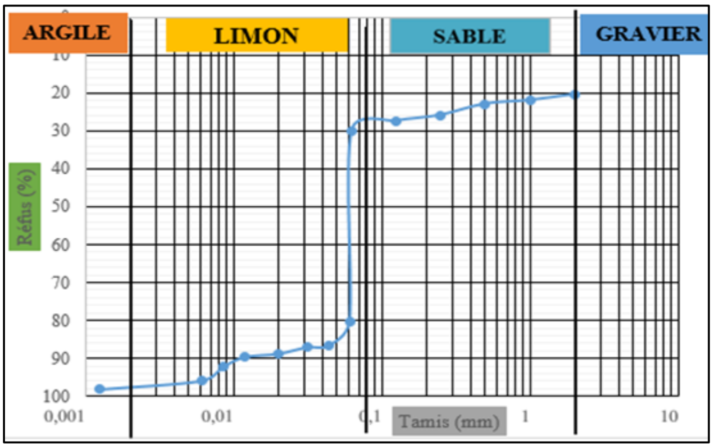


**Figure 4** Particle-size distribution curve of Anyama clay

This figure shows that the clay from Anyama is composed of two categories of grains:

- Fine fraction (particles with a diameter less than 80 µm), estimated at 74%,
- Sand fraction (particles with diameters between 80 µm and 2 mm), representing 26%.

The fine fraction consists of 3% clay particles and 72% silt. The Anyama clay therefore has a sandy–silty texture. It may contain clay minerals, which justifies determining the Atterberg limits to clarify its characteristics.

### 3.2. Atterberg Limits

The results of the Atterberg limits determined on the Anyama clay are summarized in Table 1.

**Table 1** Atterberg limits of the clay sample

| Test type | Value |
|---|---|
| Liquid limit (%) | 22 |
| Plastic limit (%) | 13 |
| Plasticity index (%) | 9 |

The water content separating the solid-state behavior domain from the plastic-state behavior domain of the Anyama clay is 13%. Likewise, the threshold separating the plastic domain from the liquid domain is 22%. These values are relatively low, suggesting that the Anyama clay contains only a small amount of clay minerals. To confirm this assumption, we examine the methylene blue value.

### 3.3. Methylene Blue Value (MBV)

The methylene blue spot test yields a methylene blue value MBV = 1.

### 3.4. Determination of Clay Nature Using Methylene Blue Value

To determine the clayey nature of the sample, the measured MBV was compared with the ranges in Table 2, which classifies soils according to the *Road Earthworks Guide.

**Table 2** Soil classification based on methylene blue value

| Soil MBV | Soil type |
|---|---|
| < 0,2 | Water-insensitive soil |
| 0,2-1,5 | Sandy–silty soil |
| 1,5-2,5 | Sandy–clayey soil, low plasticity |
| 2,5-6 | Silty soil of medium plasticity |
| 6-8 | Clayey soil |
| >8 | Highly clayey soil |

According to this classification, the MBV of this soil falls between 0.2 and 1.5, corresponding to a sandy–silty soil sensitive to water. The low methylene blue value corroborates the plasticity index. The low MBV is attributed to the absence of swelling clays in the sample (Millogo, 2008).

### 3.5. Chemical Analysis

The results of the chemical analysis are presented in an Excel table listing the chemical elements in the sample, with their proportions expressed as percentages (%) for major elements and parts per million (ppm) for trace elements. An Excel program was used to convert the analyzed elements into their respective oxides (Table 3).

**Table 3** Oxide composition of major elements

| Oxide | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|
| Content (%) | 78.13 | 14.48 | 7.39 |

This table shows that the Anyama clay is very rich in $SiO_2$ and relatively poor in $Al_2O_3$ and $Fe_2O_3$. The variation in chemical composition can be explained by environmental factors influencing the laterization process, such as climate, topography, vegetation, and parent rock. The Anyama clay was sampled in southern Côte d'Ivoire, in an Attié-type climate with heavy rainfall and very rugged relief, resulting in soil depletion in iron. As Anyama is a sedimentation zone, there is therefore a significant input of silica.

### 3.6. Formulation of Composite Materials

#### *3.6.1. Formulation of the Coating*

The mortar formulation consisted of 92% clay by mass and 8% cement by mass. The mixing water content was 60% of the clay–cement mixture to obtain a fluid mortar.

#### *3.6.2. Formulation of Rice Straw Bales*

Well-dried straw during harvesting, baling, and storage is key to the durability and strength of straw-bale walls. The moisture content of the bale at purchase and installation should not exceed 15%. The straw used must not contain grains or grain residues. The prepared straw bale had a mass of 320 g. The physical characteristics of this rice straw bale are presented in Table 4.

**Table 4** Physical characteristics of the rice straw bale

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

## 4. Conclusion

This work allowed the development of a new material made from agricultural waste (rice straw) and clay to reduce environmental pollution. To combat global warming, measures are being taken to limit environmental pollution, bringing earth-based materials back into construction. Over time, many earth-based construction techniques have emerged, including adobe, rammed earth, cob, straw–earth, bauge, molded earth, extruded earth, compressed earth, etc. The use of plant fibers as construction materials is growing, as exemplified by the rice straw studied here. Straw supports several construction systems, including thatch, straw bales, compressed straw panels, load-bearing bales, timber frame and post-beam structures, tensioned cells, and the GREB technique. In this context, a new composite material based on rice straw and clay was developed. Its fabrication followed three main steps: production of straw bales, preparation of the coating, and implementation of the composite material.

## 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] AFNOR (1980). Soil: identification and testing—determination of Atterberg limits using the Casagrande cup and plastic limit by rolling. French Standard, NFP94-051, Paris, France, 32 p.

[3] AFNOR (1992). Soil: identification and testing—particle-size analysis of soils using the sedimentation method. French Standard, NFP94-057, Paris, France, 20 p.

[4] Akoua, C.K., Yao, P.A.F., N'goran, J.P.Y., Mondé, S., & Aka, K. (2016). Sedimentological and mineralogical characterization of Tertiary-Quaternary formations in the Anyama region, southern Côte d'Ivoire. European Scientific Journal*, 12(3), 23–38.

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

[6] 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.

[7] Kouadio, K.C. (2010). Development and characterization of cement-stabilized clay blocks (CIMARG). Influence of the addition of deflocculants on the physical and mechanical properties of the blocks. Doctoral thesis, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire, 188 p.

[8] Kouakou, C.H. (2005). Valorization of Ivorian clays: Study of the stabilization of compressed clay blocks with hydraulic binders. Doctoral thesis, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire, 186 p.

[9] Millogo, Y. (2008). Geotechnical, chemical, and mineralogical study of clayey and lateritic raw materials from Burkina Faso improved with hydraulic binders: application to civil engineering (buildings and roads). Doctoral thesis, Université de Ouagadougou, Ouagadougou, Burkina Faso, 144 p.

[10] Mounir, S., Maaloufa, Y., Cherki, A.B., & Khabbazi, A. (2014). Review of thermal properties of the clay/granular cork composite material. Construction and Building Materials, 5, 183–190.

[11] Toure, P.M. (2018). Eco-construction in the tropical climate context: from material scale to building scale. Doctoral thesis, Université Cheikh Anta Diop de Dakar, Dakar, Senegal, 147 p.