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Preliminary Hygrothermal Characterization of Earth-Sand-Typha Plasters Based on Local Resources for Crinting Roofs

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Abstract

This research examines the initial hygrothermal properties of plasters composed of clay soil, sand, and Typha fibers, intended for use in crinting roofs. Five formulations containing from 0 to 9.5% Typha were studied to evaluate the influence of fiber incorporation on density, moisture content, thermal conductivity, and thermal effusivity. The results show that increasing the Typha content leads to a decrease in density, from 1840 to 1490 $kg \cdot m^{-3}$, and in thermal conductivity, from 0.79 to 0.43 $W \cdot m^{-1} \cdot K^{-1}$. Concurrently, the moisture content measured after drying increases from 2.6 to 5.6%. These results demonstrate that the incorporation of Typha improves the insulating properties of the plasters while modifying their moisture behavior. The F4 formulation (7.5% Typha) offers a promising compromise between reduced thermal conductivity, decreased density, and moderate water content. However, further tests of durability, adhesion, capillary absorption, and watertightness are essential to confirm the ability of these mixtures to waterproof crinting roofs.

Keywords

Typha, Plaster, Earth, Thermal

1. Introduction

Sub-Saharan Africa's construction sector faces a major challenge: developing sustainable solutions to meet the growing demand for infrastructure, fueled by urbanization and rapid population growth, while significantly reducing its already substantial environmental impact [1]. Indeed, 75% of energy consumption and greenhouse gas emissions in Africa come from the construction sector [2]. Currently, most buildings are designed without consideration for their climatic environment, using polluting materials whose production emits significant amounts of greenhouse gases [3]. This is particularly true in Sahelian and tropical climates, where construction techniques appear to be modeled on those of countries with a temperate climate [2]. This contrasts with vernacular and traditional buildings, which integrate better into their surroundings and are more environmentally friendly thanks to the use of local materials [3]. Clearly, a shift in architectural, material, and construction choices is necessary [2]. Applying a sand and clay-based waterproofing coating to a traditional plant-based crinting, which is not typically waterproof, would drastically reduce greenhouse gas emissions related to transportation. Furthermore, these local materials, both abundant and affordable, require only rudimentary tools for their extraction, processing, and application [4]. They are therefore perfectly suited to local labor or self-construction, making them accessible to lower-income populations [4].

Nevertheless, the use of clay soils in construction has considerable drawbacks, notably their tendency to crack during drying. [5], after comparing eight scientific articles on the subject, note that the addition of plant fibers improves compressive strength by between 4 and 117% compared to an unstabilized mixture (median of 26%). In this context, cattail fibers appear very promising. Indeed, this invasive plant causes problems on several levels, including water supply security, natural hazard prevention, biodiversity, economic activities, and public health [2]. Strategies aimed at limiting cattail proliferation over the past three decades have proven ineffective [2]. Using cattail in construction projects would provide an incentive for the population to help reduce its population. Furthermore, using fibers in construction allows for carbon sequestration, thus avoiding their use for energy production through combustion, which remains a common practice [5].

Despite these fiber reinforcements, the clay's sensitivity to moisture is a major limitation for its application as a roofing coating. Indeed, as the clay's water content increases, its volume increases and its durability decreases; conversely, during drying, water shrinkage can cause cracks that weaken its strength and provide a direct pathway for water to penetrate the core of the material during subsequent rainfall [6]. This research aims to characterize, test, and evaluate crinting roofing coatings composed of clay soil, sand, Typha, and water, in order to study their potential use as a local and ecological solution.

2. Site Presentation

Tests were conducted on Carabane Island using laterite from Mlomp and sand from Carabane. **Figure 1** shows the location of the two areas where the mineral materials were collected.

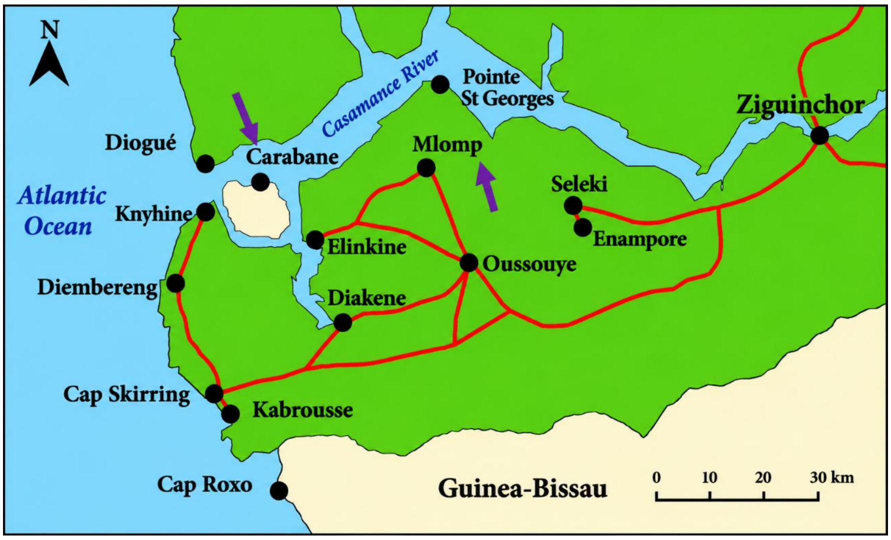

Figure 1. Location of the Carabane sand and Mlomp laterite sampling sites [7].

3. Materials and Methods

3.1. Mineral Materials

Figure 2 shows the mineral materials to be used for the formulation of the roof coating: Carabane sand (a), Mlomp laterite (b).

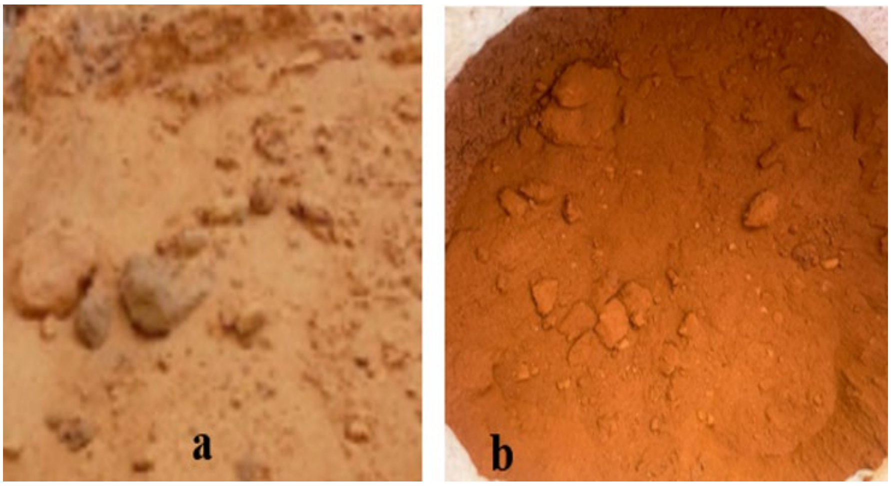

Figure 2. Mineral materials to be used for the formulation of the roof coating: Carabane sand (a), Mlomp laterite (b).

3.2. Plant Fibers

Typha is a stem plant rich in structural fibers, making it a prized building material in Africa. As a fiber, it reinforces the mixture like a rebar, increasing tensile strength and limiting cracking during drying. Furthermore, typha reduces the density of the plaster, improving its technical performance. The typha (Figure 3) used for this project came from the company Elementerre. It was sun-dried, then coarsely ground before being ground more finely using a 0.5 mm - 1 mm sieve.

We used typha fiber from the Elementerre company in Gandighal (Mbour) for mixing with mineral materials [8].

Figure 3. Therepreparing typha.

Figure 4 shows the crinting panel intended for the exploratory application of formulation F4.

Figure 4. Crinting panel.

Figure 5 shows the wooden structure where we will place the crining panels.

Figure 5. Wooden structure.

3.3. Methods

The preparation of the plasters required a mixture of Mlomp clay soil, treated sand, Typha fibers, and water, with precise measurements taken using an electronic balance and particle size controlled by sieving. The water was measured using graduated containers, and the various components were mixed in a container to obtain a homogeneous mixture. Trowels, spatulas, and floats were used for preparing, applying, and smoothing the plasters. For each formulation, three samples were prepared, for a total of fifteen samples. After application to the crinting panels, the plasters were left to dry naturally under the ambient conditions of Mlomp, Casamance, during the month of June. After this drying period, the samples intended for thermal testing were cut to dimensions of $10 \times 10 \times 2$ cm^3. The data presented are the average of three dried samples. Thermal and density measurements were carried out under equilibrium conditions with the environment of the mlomp site at the time of the tests, following natural drying of the test specimens.

No lime or other chemical stabilizer was added to the formulations. The mixtures consisted exclusively of Mlomp clay soil, treated sand, Typha fibers, and water.

3.4. Physical Tests

The physical properties of the materials, namely density and moisture content, were evaluated. Density was calculated as an average across the samples by composition, based on precise weighings to the hundredth of a gram and dimensions measured with calipers to the hundredth of a millimeter. The moisture content of the coatings was deduced from the mass loss observed after 24 hours of drying at 105˚C [9].

3.5. Asymmetrical Hot Plane

The hot plate method is an adaptation of the hot wire method to a flat geometry. The principle involves using a simple, thin electrical resistor. A thermocouple consisting of two wires, each 0.03 mm in diameter, is attached to the surface of the probe approximately at its center. This probe is inserted between the sample of the material to be characterized (bricks measuring 10 × 10 × 2 cm^3) and a polystyrene block of the same cross-section and 4 cm thick. Contact between all the elements is ensured by a clamp, which must be properly tightened after the various elements are stacked. The heating element is subjected to a voltage step of 8 volts, generating a flux density in the sample, and the temperature is recorded over time via the thermocouples. The flat heating surface emits a constant heat flux step, and the temperature evolution is recorded at the center of this same resistor, in which a thermocouple has been placed. During the period when the disturbance does not reach the other faces (the time during which the temperature remains constant), the heat transfer at the center of the sample can be considered unidirectional. Modeling heat transfer with the Pico software allows us to calculate the evolution of the temperature at the center of the sample over time. The effusivity and thermal conductivity parameters are then determined using the Matlab program (Figure 6).

Figure 6. Data acquisition method.

3.6. Formulation of Coatings

Since laterite makes up 50% of the dry formulation, an increased presence of Typha should raise the water-to-water ratio. Indeed, plant fibers, being more hydrophilic, require more water to maintain comparable workability.

$$\frac{M_{\text{eau}}}{M_{\text{laterite}}} \tag{1}$$

Table 1 represents the different formulations for coating tests in mass percentage.

Table 1. Coating formulations.

Formulation	Clay soil (%)	Treated sand (%)	Typha (%)	Report Water/Laterite
F1	50	50	0	0.20
F2	50	47.5	2.5	0.22
F3	50	45	5	0.24
F4	50	42.5	7.5	0.27
F5	50	40.5	9.5	0.30

Figure 7 shows the application of the different formulations in the crintings.

Figure 7. Arrangements of the different coating formulations in crintings.

The samples were then cut to the dimensions 2 × 10 × 10 cm to allow thermal characterization by the asymmetric hot plane method.

Figure 8 shows the cut samples for the characterization of the asymmetric hot plane.

Figure 8. Mixture and samples for the characterization of the asymmetric hot plane.

4. Results and Discussion

Table 2 shows the thermal characterization results of the different coating formulations.

Table 2. Results of thermal characterization of different coating formulations.

Formulation	Typha (%)	Average density (kg/m³)	Conductivity λ (W/m·K)	Effusivity (J/m²·K·s 1/2)	Average water content (%)
F1	0.0	1840	0.79	1220	2.6
F2	2.5	1760	0.69	1100	3.2
F3	5.0	1665	0.59	980	4.0
F4	7.5	1565	0.50	850	4.8
F5	9.5	1490	0.43	730	5.6

The values presented represent the average of the three samples prepared for each formulation (n = 3). **Figure 9** shows the thermal conductivity as a function of the typha content.

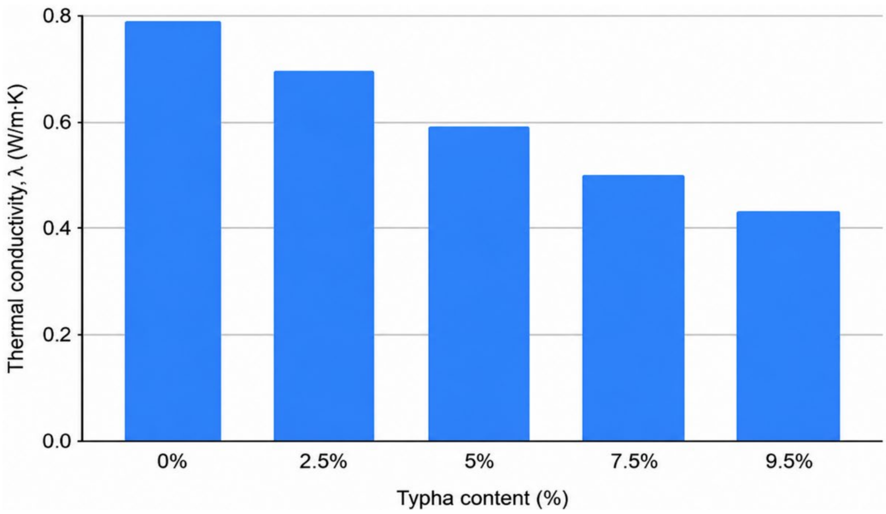

Figure 9. Thermal conductivity as a function of typha content.

The thermal conductivity of the plaster gradually decreases as the Typha content increases, from 0.79 $W \cdot m^{-1} \cdot K^{-1}$ (0% Typha) to 0.43 $W \cdot m^{-1} \cdot K^{-1}$ (9.5% Typha), a decrease of approximately 46%. The incorporation of this lightweight, low-conductivity plant material significantly improves the insulating properties of the plaster by introducing more pores and air spaces into the earth matrix, thus restricting heat conduction. This reduction in conductivity results from the low intrinsic conductivity of Typha and the increased porosity due to the fibers. Other studies on earth-fiber plasters confirm that the addition of plant fibers reduces thermal conductivity and density. These results corroborate those of Ashour *et al.* [10].

Figure 10 shows the density as a function of the typha content.

The density of the plaster gradually decreases with increasing Typha content, from approximately 1840 $kg \cdot m^{-3}$ without Typha to 1490 $kg \cdot m^{-3}$ for 9.5% Typha, representing a decrease of approximately 19%. This trend is due to the low density of plant particles compared to the mineral constituents of the matrix. The progressive incorporation of Typha replaces some of the sand with a less dense plant phase, thus promoting a more porous structure. These findings are consistent with published research on earth plasters reinforced with natural fibers, where increasing plant fiber content leads to a decrease in dry density, and where studies on clay plasters with olive fibers have also revealed a decrease in density and an increase in porosity. These results correlate with the work of Taha and Ashour *et al.* [10].

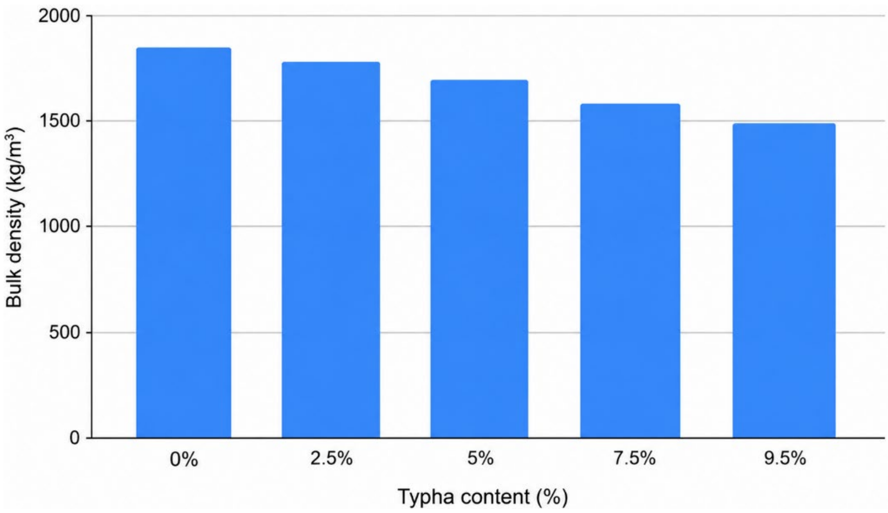

Figure 10. Density as a function of typha content.

Figure 11 shows thermal conductivity as a function of density.

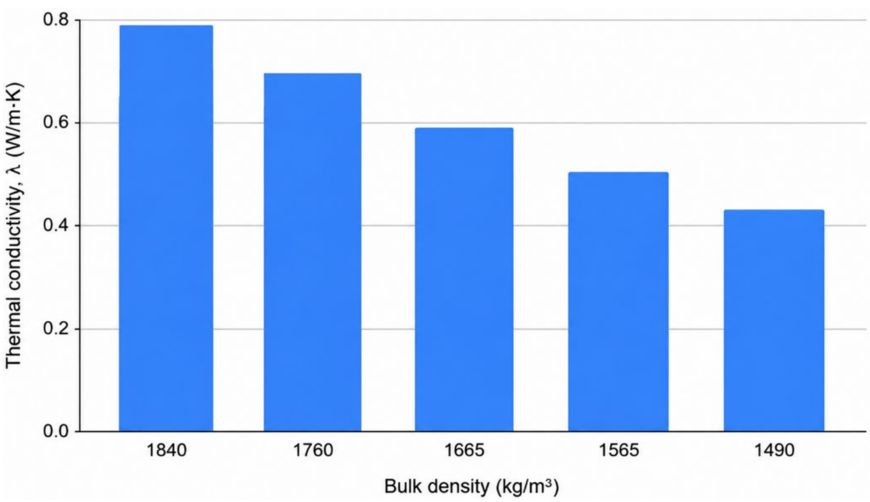

Figure 11. Thermal conductivity as a function of density.

Figure 11 highlights a significant correlation between the density and thermal conductivity of the studied formulations. Indeed, a reduction in density from 1840 to 1490 $kg \cdot m^{-3}$ is accompanied by a simultaneous decrease in thermal conductivity, from 0.79 to 0.43 $W \cdot m^{-1} \cdot K^{-1}$. This results in a clear trend: the least dense formulations exhibit the best insulating performance. This phenomenon is explained by the increase in porosity and, consequently, by the greater volume of air trapped within the matrix. Since air has a significantly lower thermal conductivity than the mineral constituents, increasing the porosity effectively limits heat transfer. This analysis is corroborated by the literature on earth-fiber materials, which emphasizes the major impact of incorporating plant aggregates on density and thermal properties. These results are therefore consistent with the conclusions established by Palumbo *et al.* [11].

Figure 12 shows the water content as a function of typha content.

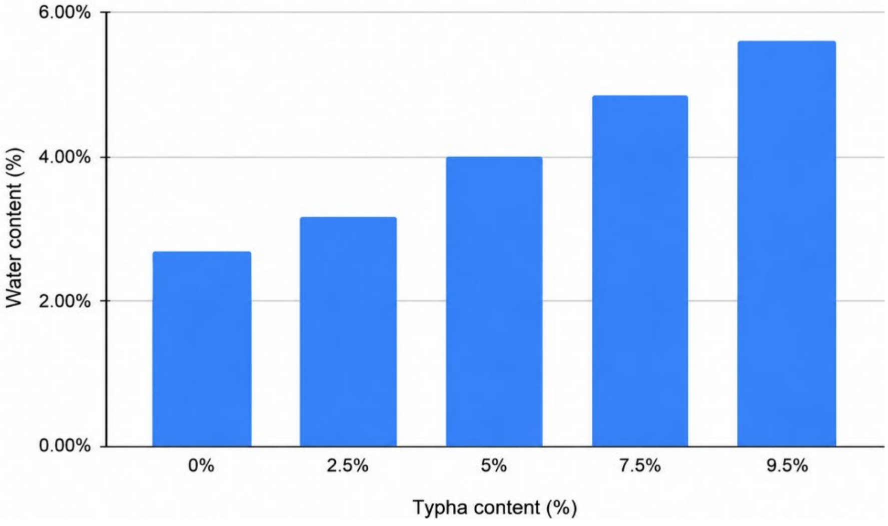

Figure 12. Water content as a function of typha content.

It is noted that adding Typha to plasters increases the measured water content, primarily due to the affinity of plant fibers for water and their porous structure. Consequently, an increase in Typha leads to a greater demand for water to maintain the plasticity of the mixture during its preparation and application. This change can be attributed to the porosity and hygroscopic nature of plant fibers. In your study, the increase in water content from 0% to 9.5% Typha, coinciding with a decrease in the treated sand fraction from 50% to 40.5%, explains the increase in water content. It is therefore a result of the increased Typha and the modification of the granular structure. This variation in moisture content is crucial for earth plasters, as it facilitates clay dispersion, adhesion to the substrate, and workability. However, excess water can exacerbate shrinkage during drying and promote cracking. It is therefore essential to find a balance between the Typha content, water demand, workability, and dimensional stability of the plaster. In short, the observed increase in water content with Typha is a logical physical behavior that must be taken into account when optimizing earth-Typha plaster formulations.

The study demonstrates that incorporating Typha significantly improves the thermal properties of plasters. Increasing the fiber content from 0 to 9.5% leads to a simultaneous reduction in density (from 1840 to 1490 $kg \cdot m^{-3}$) and thermal conductivity (from 0.79 to 0.43 $W \cdot m^{-1} \cdot K^{-1}$), thus giving the material excellent insulation capacity. These performance characteristics stem directly from Typha's low intrinsic density and increased matrix porosity, a finding perfectly consistent with the work of Ashour *et al.* [10] on earth-fiber composites. Furthermore, the decrease in thermal effusivity confirms the reduction in rapid heat transfer. Conversely, the water content of the mixture increases from 2.6% to 5.6%, a rise attributable to the hydrophilic and porous nature of the plant biomass, a typical behavior of bio-based clay matrices. Ultimately, Typha proves to be an excellent reinforcement for designing lightweight, highly insulating plasters with high hygrothermal regulation performance. Further investigations will be necessary to determine the most appropriate dosage based on thermal performance, moisture behavior, workability, and dimensional stability of the plaster, in order to guarantee the best compromise between thermal insulation, moisture management, workability, and dimensional stability. These observations are consistent with the work of Ashour *et al.* [10], who demonstrated on earth-based plasters with natural fibers that an increased fiber content reduced thermal conductivity, thus improving the material's insulation. Researchers attribute this trend to the significant influence of fibers on the thermal characteristics of the plaster. Adding up to 7.5% Typha (F4) leads to a notable improvement in the plaster's thermal properties, with a reduction in thermal conductivity from 0.79 to 0.50 W/m·K and in thermal effusivity from 1220 to 850 $J/m^2·K·s$ 1/2. This increase results in a lighter and potentially more porous material, thanks to the decrease in density. However, the F5 formulation, with 9.5% Typha, achieves the best thermal performance but has a higher water content (5.6%) and a very low density (1490 kg/m^3). An excessive amount of fibers could therefore promote moisture retention and weaken the material's cohesion. Based solely on measured hygrothermal properties, formulation F4 (7.5% Typha) was selected as the reference formulation for exploratory application on crinting, due to its compromise between reducing thermal conductivity and limiting the increase in water content. However, this selection cannot be considered a definitive optimization in the absence of mechanical testing.of waterproofing and durability.

Figure 13 shows the exploratory application of formulation F4 on the crinting panel.

Figure 13. Exploratory application of formulation F4 (7.5% Typha) on the crinting panel.

5. Conclusions

This work presents an initial hygrothermal characterization of plasters composed of clay soil, sand, and Typha fibers, intended for use on crintil roofs. Increasing the Typha content (from 0 to 9.5%) causes a gradual decrease in density (from 1840 to 1490 $kg \cdot m^{-3}$) and thermal conductivity (from 0.79 to 0.43 $W \cdot m^{-1} \cdot K^{-1}$). These results suggest improved insulating performance, attributed to the increased porosity and low density of the incorporated fibers. Concurrently, the water content measured after drying at 105˚C for 24 h increases from 2.6 to 5.6% with increasing Typha content. This trend highlights the modification of the formulation's moisture behavior linked to the incorporation of plant fibers.

Formulation F5 exhibits the best measured thermal performance, with a thermal conductivity of 0.43 $W \cdot m^{-1} \cdot K^{-1}$ and an effusivity of 730 $J \cdot m^{-2} \cdot K^{-1} \cdot s$ 1/2. However, F4, containing 7.5% Typha, was selected for exploratory application in crinting due to its compromise between thermal performance and moisture content. This selection should be considered preliminary and does not constitute a definitive optimization.

While promising for the integration of Typha into bioclimatic earth plasters, this study does not yet confirm their durability or watertightness. In-depth analyses of various technical parameters such as permeability, mechanical resistance, and moisture resistance are essential to validate their viability as roofing materials.

Author Contributions

Hamidou SY: Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, and Writing-Original Draft. Thierry Boutin: Methodology, Investigation, Experimental Characterization, Data Analysis, and Writing-Review & Editing. Ibrahima Sori Diallo: Investigation and Experimental Support. Mathioro Fall: Supervision, Validation, and Writing-Review & Editing. All authors read and approved the final version of the manuscript.

Conflicts of Interest

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

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