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RESEARCH ARTICLE

PHYSICAL AND THERMOMECHANICAL CHARACTERISATION OF MONT-ROLLAND LATERITE AND WOOD CHIPS MIXTURES STABILISED WITH PORTLAND CEMENT

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Abstract

The use of local materials, particularly laterite, is one of the most effective ways to reduce construction costs. When combined with waste materials such as wood chips, these materials also offer significant potential for improving thermal comfort in buildings. The aim of this article is to develop composites based on laterite, wood chips and a small amount of cement. These composites incorporate a fixed proportion of wood chips (5% by mass of the dry mixture), while the cement content varies between 0% and 8% by mass. Physical, mechanical and thermal tests were carried out on the different samples. The results obtained indicate that, although these composites are somewhat vulnerable to water, they offer sufficient mechanical strength to be used as infill elements in non-load-bearing walls. More specifically, composites containing 2% and 8% cement respectively have compressive strengths of 1.181 MPa and 0.765 MPa, which is approximately 25 and 16 times higher than the minimum values required for their use as non-load-bearing walls (0.0460 MPa and 0.0475 MPa). In terms of thermal performance, these materials significantly reduce the temperature on the inside of a 20 cm thick wall, with a reduction of approximately five and three times that of a conventional cement wall. These performances correspond to thermal resistances of 0.735 and 0.510 $m^2 \cdot K \cdot W^{-1}$, respectively.

Introduction:-

Senegal has experienced particularly sustained population growth over the past 50 years. The population has quadrupled in the space of five decades, from 4,997,885 inhabitants in 1976 to 18,593,258 in 2024 [1]. However, this rapid demographic growth has not been accompanied by a proportional development of infrastructure, largely due to a structurally fragile economic situation, aggravated by a succession of economic crises. This mismatch between population growth and accommodation capacity has gradually led to an acute housing crisis. Added to this problem is strong economic pressure on households, marked by a general decline in purchasing power and a

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continuous increase in the cost of traditional building materials such as cement, iron and sand. In this context, access to affordable housing is becoming a real struggle for a large part of the Senegalese population. Climate change is another aggravating factor. Due to its geographical location, Senegal is particularly exposed to rising temperatures [2]. This rise in temperature leads to significant warming of homes, prompting users to resort more and more frequently to air conditioning or mechanical ventilation systems. This phenomenon leads to a considerable increase in domestic energy consumption and, consequently, higher electricity bills, exacerbating the vulnerability of households. In this multidimensional context, this work aims to develop a building material that is both economical and thermally efficient in order to meet the combined challenges of housing affordability and climate change adaptation. The objective is to propose a sustainable solution adapted to local realities. To do this, we opted to use local resources such as laterite and wood chips (incorporated at a rate of 5% of the dry mixture), combined with a small proportion of cement, varying between 0 and 8% of the dry mixture. The first phase consisted of characterising the laterite, followed by physical and thermomechanical analyses of the laterite-wood chip-cement composites in order to evaluate their performance and potential as alternative building materials.

Materials and Methods:-

The laterite used in this work comes from the Mont-Rolland laterite quarry in the Thiès region of Senegal. The cement used, CEM II/B LL 32.5R, came from the SOCOCIM INDUSTRIES cement plant in the department of Rufisque, Dakar region, Senegal. The frake wood chips (a tropical wood species known by the scientific name, Terminalia Superba [3]) used came from the industrial zone of Pikine, Dakar region, Senegal.

The identification tests carried out on the laterite samples in accordance with standards are:

- Grain size analysis and sedimentometry [4-5]
- Atterberg limits: liquidity limit and plasticity limit [6]
- Determination of specific weight [7]

The physical, mechanical and thermal tests carried out on the laterite-chippings-cement composites in accordance with standards are:

- Loss on ignition [8]
- Water absorption and water resistance [9]
- Compressive strength [10]
- Conductivity determination using the asymmetric hot-wire method [11-12]
- Dry density [13]

The laterite-chips-cement composites were developed in a closed environment, protected from sunlight to prevent significant shrinkage during drying.

Results and Discussion:-

The grain size analysis and sedimentometry of our laterite sample (Figure 1) showed that less than 50% of the elements pass through an 80µm sieve. They also showed that the sample consists of 25% gravel, 18% coarse sand, 18% fine sand, 11% silt and 28% clay.

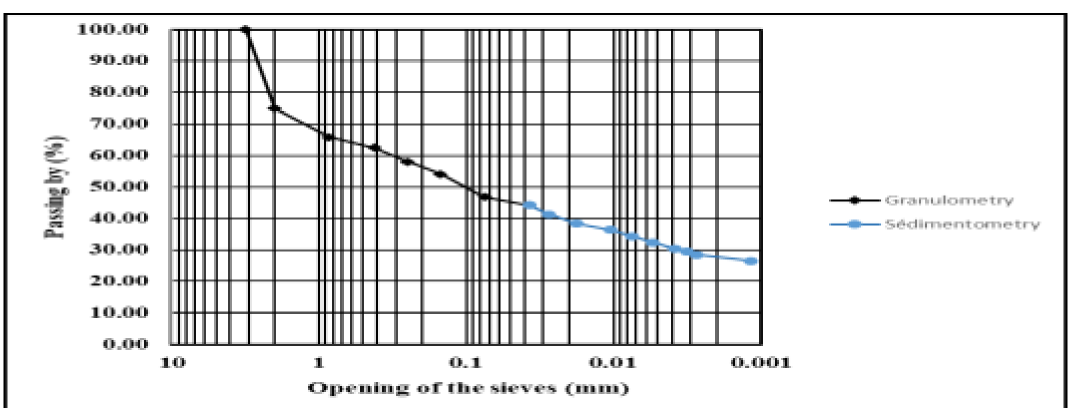


Figure1: Granulometry and sedimentometry analysis

The Atterberg limits study yielded the following results:

- Liquidity limit (W_L): 38.45%
- Plasticity limit (W_P): 20.15%
- Plasticity index (Ip): 18.30%

A plasticity index value between 12 and 25% shows that our laterite sample is a moderately clayey soil [14].
The study of the loss on ignition of the composites showed that the addition of cement results in a significant reduction in this parameter compared to composites without cement (0% cement), but also a slow increase depending on the amount of cement. From 19.92% for the composite without cement, it decreases to 17.11% at 2% cement and then increases slowly to reach values of 17.26%, 17.35%, and 17.63% at 4%, 6%, and 8% cement, respectively (Figure 2).

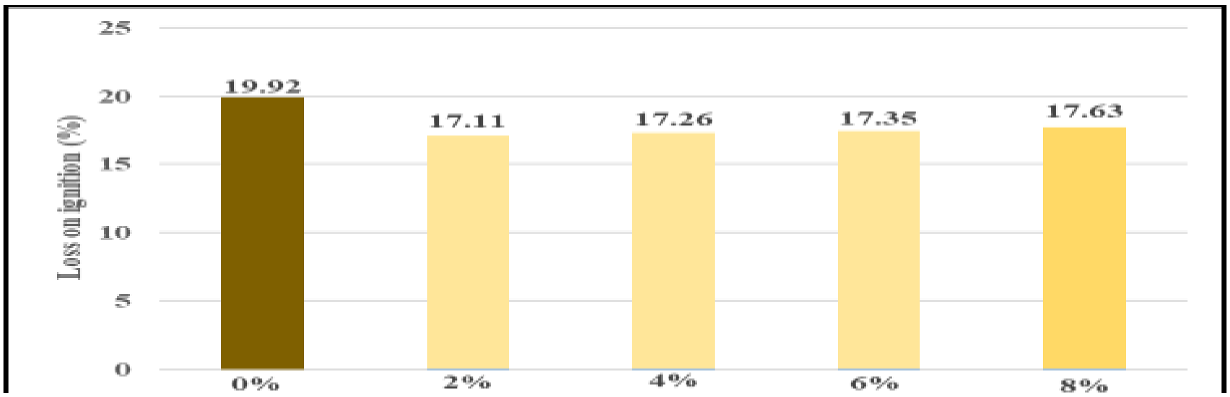


Figure2: Change in loss on ignition as a function of cement percentage

The study of the water absorption coefficient of cement-stabilised laterite-chip composites on 9.5x11x14.5 cm bricks showed that the incorporation of cement reduces this parameter. In fact, it decreases from 4.0 $Kg/(m^2. min^{1/2})$ for composites without cement to 2.9 $Kg/(m^2. min^{1/2})$ for those containing 8% cement, with a minimum value of 1.7 $Kg/(m^2 .min^{1/2})$ observed at 2% cement and values of 2.5 $Kg/(m^2 .min^{1/2})$ for dosages of 4% and 6% cement (Figure 3).

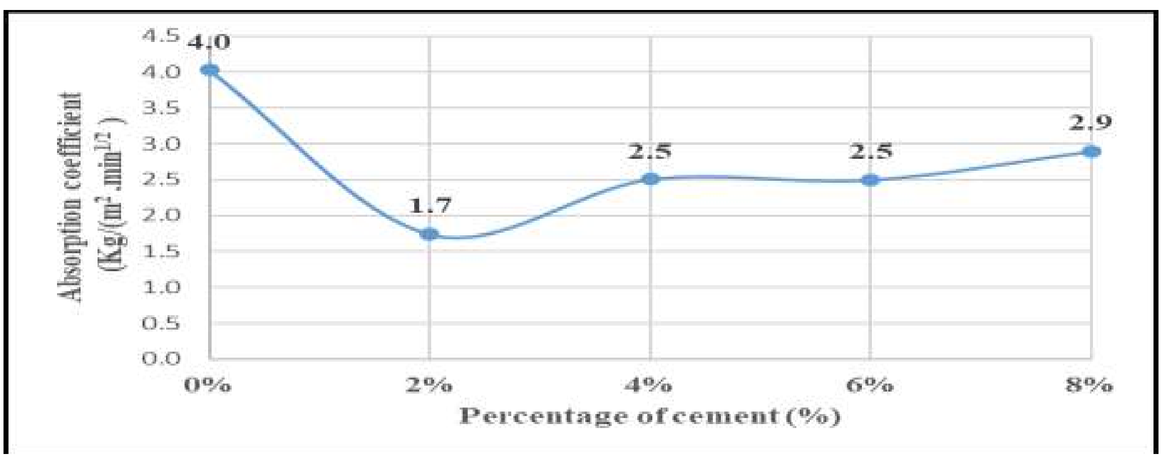
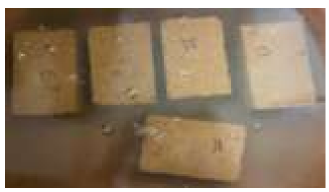


Figure3: Change in capillary absorption coefficient

With 0% cement, the material, composed solely of laterite and 5% wood chips, is very porous due to the high wood chip content. This explains the high water absorption rate observed. The incorporation of 2% cement, partially replacing the laterite, improves the cohesion of the material. More binding than laterite, cement ensures good adhesion between the different components, thus forming strong laterite-chips-cement bonds. These bonds offer better resistance to water penetration, hence the low absorption rate recorded. Above 2% cement, the absorption coefficient increases with the amount of cement, while remaining lower than that of the composite without cement. This could be explained by the fact that an excess of cement prevents homogeneous distribution, which promotes the appearance of pores. These pores facilitate water infiltration, thus leading to an increase in the absorption rate (Figure 4).

Figure4: Composite samples after capillary absorption testing

After studying the capillary absorption of laterite-chip-cement composites, it is important to also study their behaviour when immersed in water. Immersion in water of 9.5x11x14.5 cm bricks shows that their sensitivity to water is very high. After 24 hours of soaking in water, laterite-chip composites stabilised with cement percentages between 0 and 4% disintegrate completely, while those with 6% and 8% cement suffer partial damage but remain very fragile (Figure 5).



(a)

(b)

Figure 5: (a) illustration of the water resistance test; (b) after the test

Table 1 summarises the water stability results:

Table1: Water stability of composites

Cement content (%)	Laterite + 5% wood chips
0%	**Total dissolution**
2%	**Total dissolution**
4%	**Total dissolution**
6%	**Partial dissolution**
8%	**Partial dissolution**

After immersing the materials, air bubbles can be seen escaping from the composites. In reality, these bubbles are caused by the gradual replacement of the air trapped in the pores of the composites by water. This substitution process is partial at first, then becomes total over time. After 24 hours of immersion, the substitution is complete: the water has completely replaced the air, and the composites become saturated. Once this saturation is reached, the wood chips contained in the composites exceed their saturation point, causing them to swell. This phenomenon generates significant internal stresses.

Thus, regardless of the strength of the bonds between the constituents, this excess water ultimately destabilises the structure, leading to the dislocation of the materials. Furthermore, for high cement proportions (between 6% and 8%), composites show some resistance to water, although they remain relatively fragile. It can therefore be said that above a certain level, the stabilising effect of cement begins to manifest itself and improves the water stability of composites. The compressive strength of the composites was determined on 11x22cm cylindrical test pieces, and Figure 6 illustrates its evolution as a function of the percentage of cement.

The curve has two distinct parts:

- An ascending part between 0% and 2% cement, marked by an increase in compressive strength: This strength is 0.37 MPa at 0% cement and reaches 1.18 MPa with the addition of 2% cement.
- A descending section, marked by a decrease in compressive strength above 2% cement: The strength values decrease from 1.181 MPa (2% cement) to 1.09 MPa, 0.957 MPa and 0.765 MPa at 4%, 6% and 8% cement, respectively.

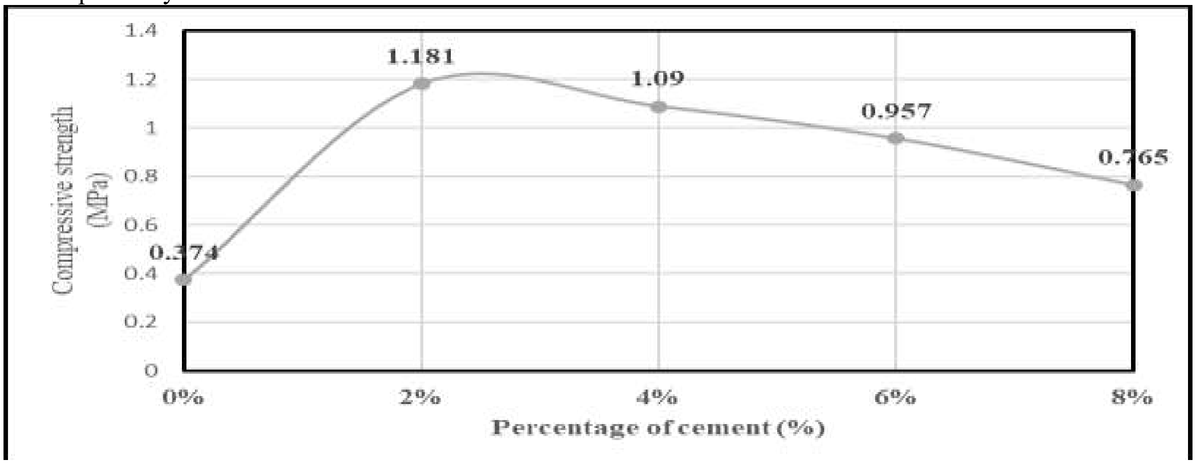


Figure 6: Evolution of compressive strength

The increase in mechanical strength observed between 0% and 2% cement for the different composites can be attributed to a sufficient quantity of cement, thus ensuring good cohesion and optimal homogeneity of the composites. In fact, the laterite used contains less than 50% fine particles, including 28% clay particles. With this proportion of fines, a small amount of cement, approximately 2%, is sufficient to ensure good cohesion of the composites. In this case, the cement fully plays its role as a stabiliser, which explains the increase in mechanical strength observed. However, above 2% cement, the decrease in strength could be due to an excessive amount of cement, disrupting the homogeneity of the composites and leading to a deterioration in their mechanical properties.
The study of the thermal conductivity of laterite-chip-cement composites on 10x10x3cm test specimens yielded the following results (Figure 7). These results showed that the addition of Portland cement leads to an increase in thermal conductivity, depending on its quantity in the mixture. Thermal conductivity increases from 0.205 $W.m^{-1}.K^{-1}$ with 0% cement to 0.392 $W.m^{-1}.K^{-1}$ with 8% cement, with intermediate values of 0.272 $W.m^{-1}.K^{-1}$, 0.291 $W.m^{-1}.K^{-1}$ and 0.326 $W.m^{-1}.K^{-1}$ respectively at 2, 4 and 6% cement.

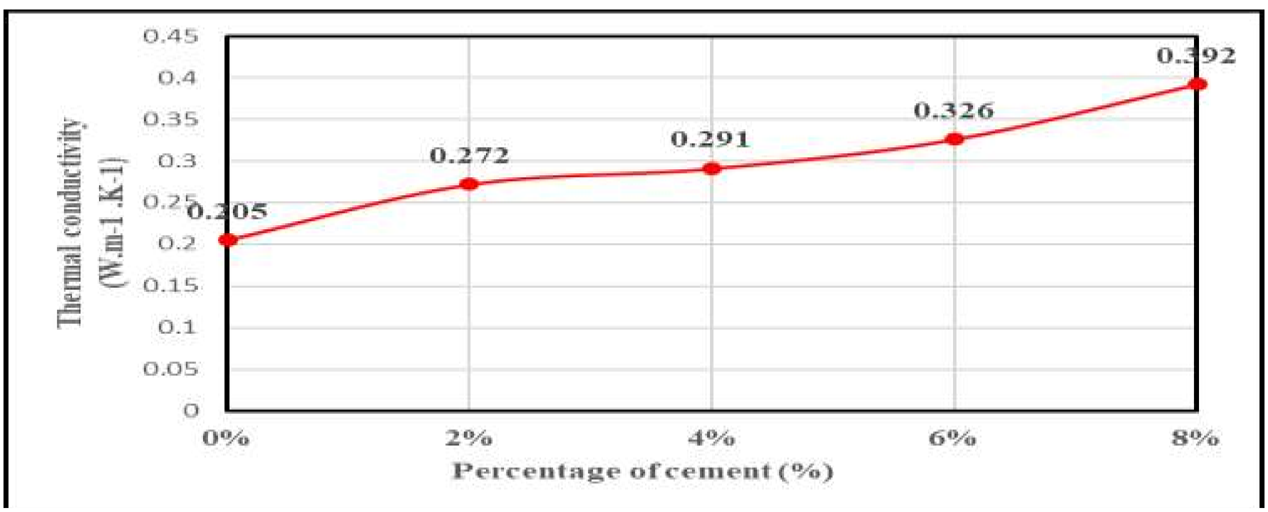


Figure 7: Evolution of thermal conductivity

In the rest of this article, we will continue our studies with composites composed of 2% and 8% cement, which have the best thermomechanical and physical characteristics, respectively. The study of the dry density of the composites gave values of 1563 kg/m³and 1614 kg/m³ for the composites with 2% cement and those with 8% cement, respectively. The mechanical strengths required (Table 2) for the use of these different composites in construction as 3-metre-high infill walls (non-load-bearing walls) were calculated using equation (1). The required strength is that which a brick should have when supporting loads generated by other bricks above it (Figure 8).

$$\boldsymbol{Required\ strength\ (MPa) = dxgxH} \qquad (1)$$

Where:
d = dry density of the composite in kg/m^3
g = acceleration due to gravity in m/s^2
H = Height of the wall above in metres

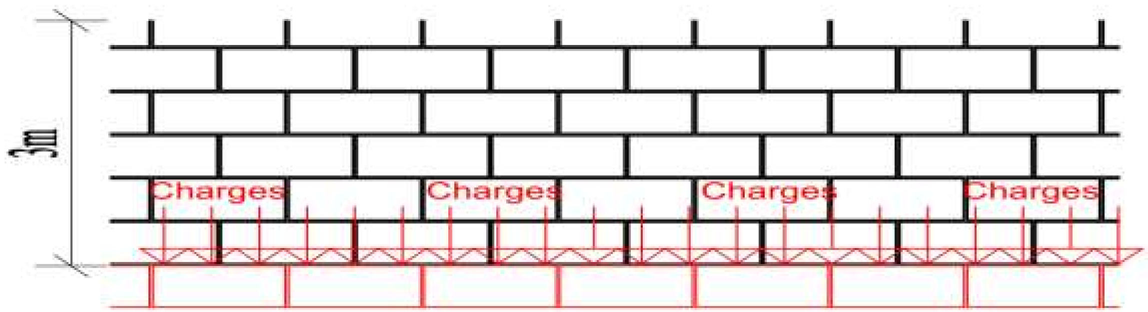


Figure 8: Illustration of loads

Table2: Required strength

	Cement content	
	2% cement	8% cement
Required strength in MPa	0.0460	0.0475

The compressive strength required for the use of composites stabilised with 2% cement as non-load-bearing walls is estimated at 0.0460 MPa, while that required for composites stabilised with 8% cement is 0.0475 MPa.Furthermore, the strength measured for composites with 2% cement is 1.181 MPa, which is more than 25 times the required strength. For composites stabilised with 8% cement, the strength obtained is 0.765 MPa, which is more than 16 times the minimum expected value. From a mechanical point of view, the mechanical strengths are more than sufficient for the composites to be used as infill walls. From a thermal perspective, the determination of the thermal resistance of the two different composites on a 20 cm thick wall yielded the results shown in Table 3 (Figure 9). These results are compared with those obtained on a cement wall (approximately equal to 0.16 $m^2.K.W^{-1}$[15])and on a wall made solely of laterite,as determined by **Diouf et al., 2023** (equal to 0.261 $m^2.K.W^{-1}$) [16].

Table3: Thermal resistance of different composites

	Thermal resistance $m^2.K.W^{-1}$
Laterite-chips-2% cement (LCC2)	0.735
Laterite-chips-8% cement (LCC8)	0.510
Cement (C)	0.16
Laterite only (L)	0.261

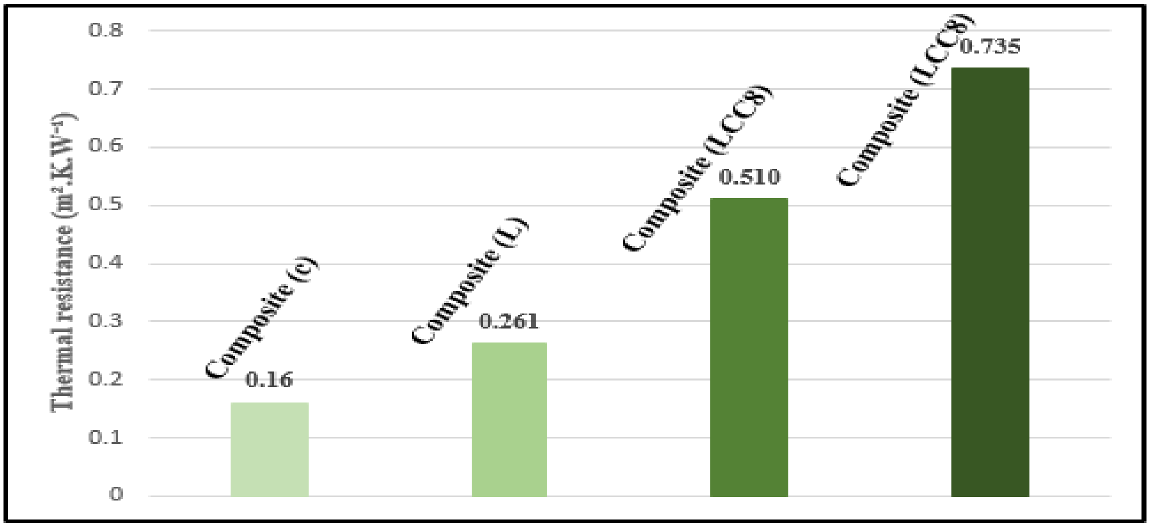


Figure9: Evolution of thermal resistance

With these different thermal resistances, equation (2) allows us to calculate the heat flux on the walls per unit area.

$$\varphi = \frac{\Delta T}{Rth} \qquad (2)$$

Where:

φ : heat flux in W/m^2

ΔT : difference in temperature between the exterior and interior in Kelvin (K)

Rth : Thermal resistance in $m^2.K.W^{-1}$

For walls placed in the same environment with the same heat flow and the same external temperature, using the equation, we can compare the temperature differenceΔT of composites L, LCC2 and LCC8 with that of cement. Equation (3) can be deduced from equation (2):

$$\Delta T(L) = \frac{Rth(L)}{Rth(C)} \Delta T(C) \qquad (3)$$

Where:

ΔT (L) : temperature difference Text – Tint of a laterite wall only (composite L)

ΔT (C) : Temperature difference Text – Tint of a cement wall (composite C)

Rth (L) : Thermal resistance of a laterite wall only (composite L)

Rth (C) : Thermal resistance of a cement wall (composite C)

By applying the equation numerically to all composites, we obtain the following relationships:

$$\mathbf{\Delta T(L) = 1.63125x\Delta T(C)}$$
$$\mathbf{\Delta T(LCC2) = 4.93575x\Delta T(C)}$$
$$\mathbf{\Delta T(LCC8) = 3.1875x\Delta T(C)}$$

These results show that, compared to the cement wall, the use of these composites reduces the temperature on the inner surface by more than 1.6 times for the laterite wall alone, more than 4.9 times for the laterite wall with chips and 2% cement, and more than 3.1 times for the laterite wall with chips and 8% cement.

Conclusion:

This study is part of an initiative to promote bio-based materials, with the aim of reducing both construction costs and the carbon footprint of buildings. Several significant results were obtained at the end of this study. In terms of mechanical properties, composites based on laterite and wood chips, incorporating 2% and 8% cement respectively, demonstrated remarkable performance. Their mechanical strength is approximately 25 times and 16 times higher than the thresholds required for use in construction, confirming their structural suitability. Thermally, these same composites have notable insulating properties. Compared to a reference composite such as cement mortar, they reduce indoor temperatures by an estimated 4.9 times for the 2% cement composite and 3.1 times for the 8%

composite. These results suggest that cement-stabilised laterite-chip composites are a sustainable, economical and energy-efficient alternative for construction in hot climates.

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