

Mechanical Characterization and Literature-Based Thermal Review of Typha Australis Fiber-Reinforced Earth Composites for Ecological Building Construction

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Abstract

This study investigates the valorization potential of Typha australis fibers in earth-based composites intended for ecological building construction in sub-Saharan Africa. The composite specimens were prepared by progressively substituting laterite with Typha australis fibers at dosages ranging from 0% to 7% by mass in a multicomponent earth matrix comprising laterite, kaolin, limestone (calcaire), and dune sand. Specimens were compacted using the Standard Proctor method and subjected to uniaxial compressive strength (UCS) tests after a 7-day curing period. The results demonstrate that the addition of Typha fibers significantly influences the mechanical performance of the composite. Compressive strength increased progressively from 2.15 MPa (0% Typha) to a maximum of 2.86 MPa at a 4% fiber dosage, representing a 33% improvement. Beyond this threshold, mechanical strength declined. The thermal behavior of the composites is discussed on the basis of measurements performed on pure Typha specimens and literature data on Typha-based composites; direct thermal conductivity measurements on Proctor-compacted earth-Typha specimens are recommended in future work. The mean thermal conductivity of Typha australis alone was measured at 0.045 W/m·K, confirming its excellent insulating potential. Physical and geotechnical characterization of raw materials—including particle size distribution, Atterberg limits, specific Gravity, and bulk density—revealed suitable properties for composite formulation. These findings suggest that an optimum Typha fiber content of 4% maximizes mechanical performance under the reported laboratory conditions, while higher contents (5% - 7%) are expected to favor thermal insulation, enabling tailored composite design for structural or insulating applications. This work contributes to the promotion of locally sourced, low-carbon

building materials in tropical regions.

Keywords

Typha Australis, Earth Composite, Compressive Strength, Thermal Conductivity, Biosourced Materials, Ecological Construction

1. Introduction

The construction sector is one of the world's leading consumers of energy and emitters of greenhouse gases. In sub-Saharan Africa, buildings account for approximately 80% of final energy consumption—excluding firewood and biomass—and this share is projected to grow significantly as a result of rapid urbanization, population growth, and rising household incomes [1]. In Senegal, nearly 90% of electricity generation relies on imported fossil fuels, making energy efficiency in buildings an urgent priority [2].

Against this backdrop, the development of biosourced building materials using locally available plant resources has gained considerable momentum worldwide. Plant fibers incorporated into earth composites offer dual advantages: improved mechanical performance through fiber reinforcement and enhanced thermal insulation owing to the high porosity and low density of vegetal matter [3] [4] [5]. Among the most promising local resources in Senegal is *Typha australis* (commonly known as cattail or bulrush), a proliferating aquatic macrophyte that colonizes the wetlands of the Senegal River Delta and other water bodies throughout West Africa. Left unmanaged, *Typha* forms dense monocultures that disrupt aquatic ecosystems, impede navigation, and block irrigation canals [6]. Its large-scale harvesting for construction therefore, simultaneously addresses an ecological nuisance and a socioeconomic opportunity.

Previous research has demonstrated that *Typha australis* fibers possess physical and morphological characteristics comparable to those of flax fibers, including a density of approximately 1.53 g/cm³ and a moisture content of 6% - 10%, making them suitable for composite reinforcement [7]. Thermal measurements on pure *Typha* specimens have yielded a mean thermal conductivity of 0.045 W/m·K, well below the 0.065 W/m·K threshold that qualifies a material as a thermal insulator [8]. Furthermore, preliminary studies on *Typha*-cement-sand composites have shown that even small fiber additions (0.5% - 3%) substantially reduce thermal conductivity [8].

However, the combination of *Typha* fibers with a multicomponent earth matrix comprising laterite, kaolin, limestone, and dune sand has not been systematically investigated. Such a formulation is particularly relevant for the West African context, where these raw materials are abundantly and locally available, and where compressed earth blocks (CEB) and adobe constructions remain widespread. The present study addresses this gap by conducting a comprehensive geotechnical

characterization of each raw material and evaluating the mechanical and thermal behavior of the resulting earth-Typha composite across a range of fiber dosages (0% - 7% by total mass).

The specific objectives of this work are: 1) to characterize the physical and geotechnical properties of all constituent materials; 2) to formulate earth-Typha composite specimens using the Standard Proctor compaction procedure; 3) to determine the uniaxial compressive strength (UCS) of specimens as a function of Typha fiber content; and 4) to discuss the thermal implications of varying fiber dosage on the basis of direct measurements on pure Typha specimens and published data on Typha-based composites, pending direct thermal characterization of the earth-Typha composites in future work.

2. Materials and Methods

2.1. Raw Materials

All raw materials were sourced from Senegalese localities to reflect realistic construction practice. Dune sand was obtained from Bambilor (Dakar region), kaolin from Thiès (Thicky site), limestone (calcaire 0/3) from Rufisque, and laterite from Thiès. Typha australis stems were harvested from the Wakhinane Nimzat wetland area in Dakar. Water was supplied by the Société Sénégalaise des Eaux (SDE).

After harvest, Typha stems were sun-dried for at least seven days to ensure complete moisture evaporation, then mechanically chopped into short fibers of 5 - 20 mm length using a mechanical cutter; fibers were subsequently screened through a 20 mm sieve to remove oversized fragments and ensure uniform dispersion within the matrix. Laterite, kaolin, and limestone were dry-sieved through a 2 mm mesh to ensure a homogeneous texture prior to mixing.

2.2. Composite Formulation and Specimen Preparation

Composite mixtures were designed according to a total dry mass of 2500 g per Proctor mould. The reference (control) mixture consisted of: laterite 1100 g, kaolin 500 g, limestone 500 g, and dune sand 400 g. This matrix composition was selected on the basis of preliminary trial mixes that balanced plasticity, workability, and sufficient cohesion for Proctor compaction. Typha fibers were introduced by substituting an equivalent mass of laterite, at dosages of 1%, 2%, 3%, 4%, 5%, and 7% of the total dry mass, corresponding to 25, 50, 75, 100, 125, and 175 g of fiber, respectively. The water content of all mixtures was fixed at 12% (300 mL), corresponding to the optimum moisture content (OMC) determined by the Standard Proctor compaction test (NF P 94-093) performed on the reference matrix, which yielded a maximum dry density of approximately 1.85 g/cm³. This single water content was applied to all dosage levels to isolate the effect of fiber content on strength, acknowledging that the OMC may shift slightly with increasing fiber addition.

The fabrication protocol followed four stages: 1) dry-mixing of laterite, limestone, Typha, and dune sand; 2) preparation of a kaolin slurry by mixing kaolin

with the measured water; 3) combining the dry mix and the kaolin slurry; and 4) compaction using the Standard Proctor procedure (NF P 94-093) in cylindrical moulds (diameter: 100 mm, height: 110 mm). Three replicate specimens were prepared for each dosage level.

2.3. Uniaxial Compressive Strength Test

Compressive strength tests were performed 7 days after specimen fabrication using a concrete compression press. The uniaxial compressive strength (σ) was calculated as:

$$\sigma = F/A \quad (1)$$

where F is the peak applied force (N) and A is the cross-sectional area of the specimen (mm^2). For each dosage, the mean compressive strength was calculated from the three replicates. Results were compared against the minimum load-bearing threshold of 150 daN (≈ 1.91 MPa) specified by NF P14-301 for structural hollow blocks.

2.4. Thermal Characterization

Thermal conductivity was determined by the heat-flow box method using prismatic specimens ($270 \text{ mm} \times 270 \text{ mm} \times 50 \text{ mm}$) composed of 100% chopped *Typha australis* at varying bulk densities. For fiber-earth composites, thermal conductivity was assessed on cement-sand-Typha specimens (cement: 15.8%, water: 8.05%, sand: 76.14%) with Typha additions of 0.5% to 3% [8]. These reference values informed the thermal interpretation of the earth-Typha results.

3. Results and Discussion

3.1. Geotechnical Characterization of Raw Materials

3.1.1. Particle Size Distribution

Sieve analysis revealed distinct granular profiles for each material. The dune sand exhibited a stepped grading curve characteristic of medium-grained sands deficient in intermediate particle sizes, with 91.5% of particles passing the 0.1 mm sieve. The laterite showed well-graded behavior with particles distributed across the full sieve range (0.08 - 16 mm), including a coarse fraction (19.6% retained on the 16 mm sieve), indicating good granular interlocking potential. The kaolin was essentially composed of fine particles (<0.315 mm), with 99.5% passing the 0.08 mm sieve, reflecting its phyllosilicate mineralogy. The limestone (calcaire 0/3) presented a broadly distributed granulometry from 0 to 10 mm, with 61.4% passing the 0.08 mm sieve, confirming its role as a gap-filling aggregate.

3.1.2. Atterberg Limits and Plasticity

Atterberg limit tests were conducted on laterite, kaolin, and limestone. The laterite displayed a liquid limit (WL) of 44.20% and a plasticity index (IP) of 23.60, classifying it as a low-to-medium plasticity material ($\text{IP} < 50$), suitable for earth construction without excessive shrinkage risk. The kaolin exhibited markedly higher

plasticity ($WL = 90.35\%$, $IP = 57.61$), classifying it as a highly plastic and expansive clay. This property justifies its incorporation in small proportions to provide cohesion while being tempered by the other components. The limestone recorded $WL = 49.94\%$ and $IP = 22.07$, indicating low-plasticity behavior adequate for aggregate use; its moderate plasticity index reflects the fine fraction present in the 0/3 grading and does not preclude its role as a gap-filling aggregate in the composite matrix.

3.1.3. Physical Properties

Table 1 summarizes the key physical properties of all constituent materials. The specific gravity values of sand (2.661 g/cm^3), laterite (2.50 g/cm^3), kaolin (2.485 g/cm^3), and limestone (2.59 g/cm^3) are typical of silicate-based minerals. The Typha fiber bulk density was extremely low (0.044 g/cm^3), consistent with its highly porous lignocellulosic structure, which is the primary driver of its insulating capacity. The sand equivalent of $96.44\% > 80\%$ confirms the cleanliness and absence of clay fines in the dune sand.

Table 1. Physical properties of constituent materials.

Material	Specific Gravity (g/cm^3)	Bulk Density (g/cm^3)	Natural Water Content (%)	Plasticity Index (IP)
Dune Sand	2.661	1.51	0.53	—
Laterite	2.500	1.51	3.41	23.60
Kaolin	2.485	1.21	4.38	57.61
Limestone	2.590	1.33	2.14	22.07
Typha australis	1.530*	0.044	6 - 10	—

*Absolute density measured by helium pycnometry [7].

3.2. Compressive Strength of Earth-Typha Composites

Figure 1 presents the mean uniaxial compressive strength (UCS) values obtained for all dosage levels. All formulations comfortably exceeded the 1.91 MPa threshold corresponding to the normative 150 daN load-bearing requirement (NF P14-301), demonstrating the structural viability of the earth-Typha composite for construction applications.

The strength evolution followed a non-monotonic pattern with a clear optimum at 4% Typha content. This trend can be interpreted through the fiber matrix interaction mechanism: at low dosages (1% - 4%), the finely chopped Typha fibers penetrate the micropores of the earth matrix, increasing compaction density and improving particle interlocking, which progressively enhances load transfer capacity [9]. The maximum UCS of 2.86 MPa at 4% represents a 33% improvement over the control mixture (2.15 MPa), a substantial reinforcement effect attributable to the bridging action of fibers across potential crack planes.

Beyond 4%, the excess fiber volume disrupts matrix continuity: the low-density Typha material (0.044 g/cm^3) introduces a high pore volume that counteracts

compaction, reduces inter-particle contact, and creates preferential failure planes. This behavior is consistent with observations reported for other plant-fiber-earth composites, including hemp lime [10] and sisal-clay systems, where an optimal fiber content exists, beyond which strength decreases while porosity and hence thermal resistance increase [3].

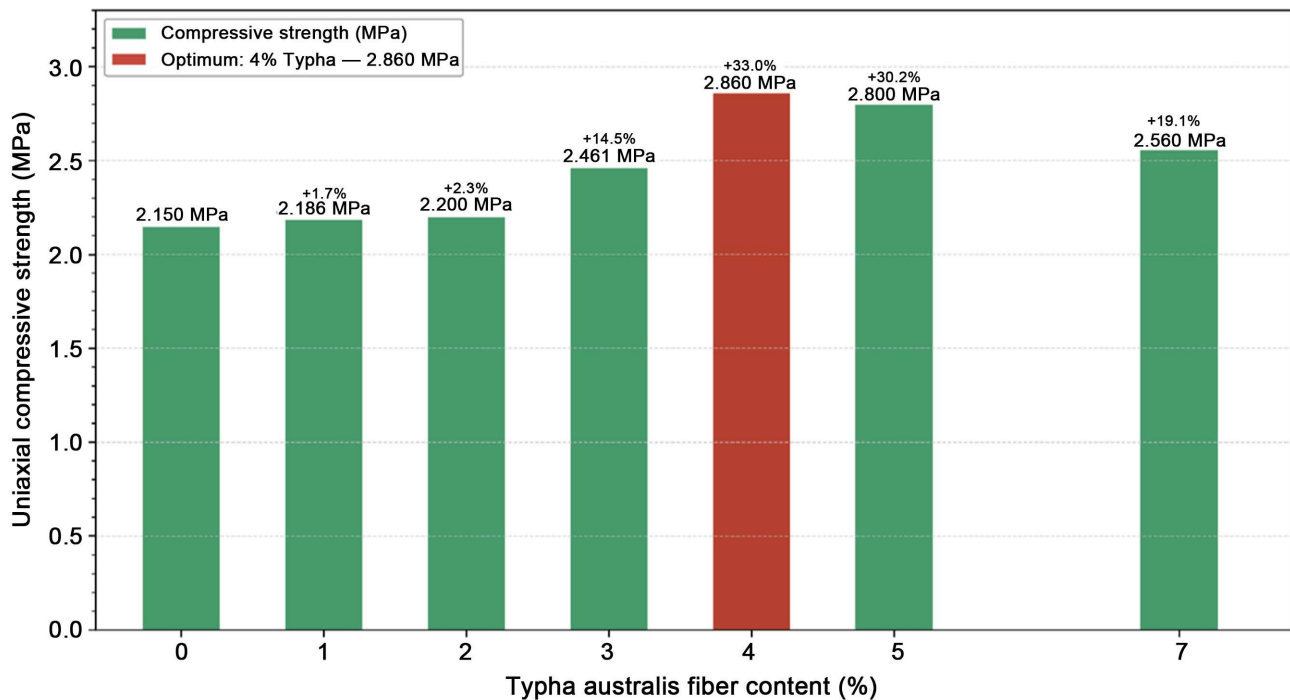


Figure 1. Mean uniaxial compressive strength of earth-Typha composites as a function of fiber content.

3.3. Literature-Based Review of Thermal Properties

The mean thermal conductivity of 100% *Typha australis* specimens was 0.045 W/m·K at a mean bulk density of approximately 69.7 kg/m³, confirming its classification as a thermal insulator ($\lambda < 0.065$ W/m·K). This value is comparable to that of hemp-lime composites (0.06 - 0.12 W/m·K) [11] [12] and loose mineral wool (0.035 - 0.045 W/m·K), positioning *Typha* as a competitive alternative insulating material [8].

In the earth *Typha* composites, the thermal behavior exhibits an inverse relationship with mechanical strength: while compressive strength peaks at 4% and declines thereafter, thermal resistance continues to improve as *Typha* content increases from 4% to 7%. This trade-off reflects the dual nature of *Typha*: its fibrous, porous structure simultaneously introduces crack-bridging reinforcement (beneficial at low dosages) and thermal barrier properties (dominant at higher dosages). Consequently, the optimal dosage depends on the intended application: 4% *Typha* is recommended where structural load-bearing capacity is the primary criterion, while dosages of 5% - 7% are more appropriate for non-load-bearing thermal insulation applications such as partition walls, ceiling panels, or external cladding.

It is important to note that in this study, the thermal conductivity of the earth-

Typha composites was not measured directly on the Proctor-compacted specimens, but was inferred from the literature data on Typha-cement-sand composites and the known trend of conductivity decrease with increasing Typha content [8]. Direct measurement of λ on earth-Typha composites using a heat-flow meter or hot-disk apparatus is recommended in future work to quantify thermal performance precisely across the full dosage range.

3.4. Implications for Sustainable Construction in Senegal

The results of this study have significant practical implications for the construction sector in Senegal and West Africa more broadly. Laterite, kaolin, limestone, and dune sand are all locally and abundantly available raw materials, while Typha australis constitutes an invasive biomass whose management represents a socio-environmental challenge. The valorization of Typha into composite building elements therefore contributes simultaneously to: 1) reducing construction costs by replacing imported materials; 2) improving the energy performance of buildings through enhanced thermal mass and insulation; 3) reducing the carbon footprint of construction by substituting cement-based products with earth composites that sequester biogenic carbon [5]; and 4) creating local economic value chains around Typha harvesting and processing.

The compressive strength values obtained (2.15 - 2.86 MPa) are consistent with, and in several cases superior to, values reported for stabilized compressed earth blocks (CEB) in the literature, which typically range from 1.0 to 3.0 MPa [13]. The compliance of all formulations with the NF P14-301 threshold is promising and suggests the preliminary suitability of earth-Typha composites as structural masonry elements in low-rise buildings under the reported laboratory conditions. However, block-scale validation, long-term durability testing (moisture resistance, freeze-thaw cycling, abrasion), and in-situ performance monitoring are required before definitive structural recommendations can be made. Beyond mechanical compliance, comparative life-cycle assessments of façade systems and thermal insulation materials across different climatic conditions further support the environmental relevance of adopting such low-impact, locally sourced solutions [14].

4. Conclusions

This study has demonstrated that Typha australis fibers can be effectively incorporated into a multicomponent earth matrix comprising laterite, kaolin, limestone, and dune sand to produce composites with enhanced mechanical and thermal properties. The following principal conclusions are drawn:

- The geotechnical characterization of raw materials confirmed their suitability for composite formulation: clean granular sand (ES = 96.44%), well-graded laterite (IP = 23.60), highly plastic kaolin (IP = 57.61), and low-plasticity limestone (IP = 22.07) collectively provide complementary mechanical and cohesive properties.

- Uniaxial compressive strength increased progressively from 2.15 MPa (0% Typha) to a maximum of 2.86 MPa at 4% Typha, representing a 33% improvement. All formulations satisfied the normative 150 daN structural threshold.
- Beyond 4%, compressive strength declined, while thermal insulation improved, establishing a trade-off between mechanical and thermal performance governed by fiber content.
- Typha australis alone exhibits a mean thermal conductivity of 0.045 W/m·K, confirming its classification as a thermal insulator and its suitability for incorporation into insulating panels.
- The locally sourced, low-carbon nature of all raw materials—combined with the invasive character of Typha—makes earth-Typha composites a compelling sustainable building solution for sub-Saharan Africa.

Future research should focus on: direct measurement of thermal conductivity of Proctor-compacted earth-Typha specimens; durability assessment, including moisture resistance, freeze-thaw cycling, and abrasion resistance; acoustic characterization; and scale-up studies for full-scale block production and field performance monitoring.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflicts of Interest

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

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