Scientific Research Publishing

Open Journal of Applied Sciences, 2025, 15(2), 517-529
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Experimental Characterization of the Thermal Properties of Thin Polypropylene Plates Reinforced with Residues and Fibers from the Borassus Wood (Rônier) of Chad

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How to cite this paper: Malgnan, A., Ngargueudedjim, K., Bassa, B., Bianpambe, H.W., and Ntamack, G.E. (2025) Experimental Characterization of the Thermal Properties of Thin Polypropylene Plates Reinforced with Residues and Fibers from the Borassus Wood (Rônier) of Chad. *Open Journal of Applied Sciences*, **15**, 517-529.
https://doi.org/10.4236/ojapps.2025.152033

Received: January 23, 2025
Accepted: February 25, 2025
Published: February 28, 2025

Abstract

This study focuses on the thermophysical characterizations of composite materials made from polypropylene reinforced with residues and fibers from Borassus wood from Chad. These properties are experimentally determined at different temperatures using the hot wire method of the "FP2C" machine, where the hot wire probe is inserted between two specimens. The values of the thermal conductivity in powdered Borassus wood range from 0.170 W/mK to 0.182 W/mK for female wood (FNTF) and from 0.169 W/mK to 0.173 W/mK for male wood. For the female and male fibers, the thermal conductivity values range from 0.137 W/mK to 0.157 W/mK for the female and from 0.138 W/mK to 0.168 W/mK for the male. The thermal effusivity of the residues and fibers of Borassus wood varies from: 509.6 $Ws^{1/2}/m^2K$ to 543 $Ws^{1/2}/m^2K$ for the powder of female wood and from 524.6 $Ws^{1/2}/m^2K$ to 547 $Ws^{1/2}/m^2K$ for the powder of male wood. For the fibers of Borassus wood, the values range from 410.6 $Ws^{1/2}/m^2K$ to 523.6 $Ws^{1/2}/m^2K$ for the female wood fibers and from 420.3 $Ws^{1/2}/m^2K$ to 480.3 $Ws^{1/2}/m^2K$ for the male wood fibers. These results are important for the applications of Borassus wood residues and fibers in construction works regarding the thermal insulation of habitats.

Keywords

Composite Materials, Residues and Fibers of Rônier Wood from Chad, Thin

Sheets, Thermal Properties, Characterization

1. Introduction

The determination of the thermophysical properties of construction materials plays a very necessary role in a large number of scientific and industrial fields [1]. This determination can be carried out using several methods, and in our case, we have chosen plant-based materials: Borassus wood [2]. These materials are currently of great interest due to the energy crisis and the housing crisis in several developing countries, particularly in Chad, where the income of a large majority of the population only allows for the construction of social economic housing [3]. Climate change, which is one of the greatest concerns of our century, necessitates the search for thermal comfort in housing. Moreover, Borassus Aethiopum is available in all regions of Chad, with a renewable nature [4]. Wood as a material requires very little energy, and the advantages of its use in construction are numerous, such as bamboo, hemp, kenaf, and oak wood [5]. The performance of Borassus in terms of thermal insulation of buildings remains scientifically little known [6] and the research on the thermal characteristics of this species is the focus of our concerns. This characterization could reduce energy consumption, environmental impacts, and ensure healthy and comfortable indoor environments, knowing that we spend 80% of our time inside the building [7].

2. Methods and Materials

2.1. Materials

The residues and fibers are collected from the trunk of male and female Borassus wood, aged approximately 30 to 40 years, felled in the Tandjilé province located between 9˚18'36" North latitude and 16˚4'45" East longitude, in the Tchoua sub-prefecture in southern Chad [8].

2.1.1. Grinding and Sieving of Residues into Untreated Flour

The residues of Borassus wood were left in the open air for two weeks to reduce the moisture and sugar content. Next, they were cut into small pieces and sent to an electric grinder of the brand Retsch Gmbh 5667 HAAN WEST-GERMANY [9] with blades at a speed of 300 rpm for 180 seconds at the laboratory of the Institute for Livestock Research and Development (IRED) in N'Djamena. The residues are ground into powder with a size ranging from 0.1 to 0.5 μm in diameter for **Photo 1**.

2.1.2. Thermal Properties of Materials

In the presence of one or more modes of heat transfer, the thermal properties of a material are quantities that characterize its behavior [10]. These properties express the behavior of the material subjected to steady-state transfers: thermal conductivity, thermal resistance, and emissivity, or subjected to dynamic transfers: thermal diffusivity and thermal effusivity. The properties governing conduction and

Photo 1. Electric machine for grinding residues into powder.

convection transfers are also called transfer properties because they are related to the agitation of atoms and molecules in the medium that carry heat. They also relate to the material's ability to absorb thermal energy [11]. This thermal energy can be absorbed to raise the temperature of the material or to transform it: heat capacity, enthalpy of fusion, thermal expansion coefficient, etc. All the thermal properties of a material depend on the nature of the body and its temperature. The measurement of these properties is inseparable from the measurement of temperature and the knowledge of the nature of the material: homogeneous or isotropic. The measured values or the relationship of the quantity as a function of temperature [12] are given by the equation:

$$\boldsymbol{grad}\left(T\right)=\boldsymbol{n}\frac{\partial T}{\partial n} \tag{1}$$

2.1.3. Thermal Conductivities

In physics, thermal conductivity is the quantity introduced to measure the ability of a substance to conduct heat in a construction material. In steady state, in the simplest case of one-dimensional heat flow through a homogeneous wall of thickness e and uniform temperatures T_1 and T_2, the heat flux Φ is expressed in the form [13].

$$\varphi=\frac{\lambda}{e}\times\left(T_1-T_2\right)\times S \tag{2}$$

where:

S is the area of the lateral faces in m^2;

e is the thickness of the sample in m;

Φ is the heat flow in W.

$$\lambda=\frac{\varphi\times e}{S\times\left(T_1-T_2\right)} \tag{3}$$

T_1-T_2: the temperature difference in Kelvin (K).

Thermal conductivity measures the ability of heat to pass through a body more or less easily in a steady state. It depends on the nature of the material and its temperature [14]. The thermal conductivity of wood directly depends on its density, moisture content, and the considered direction, either parallel to the fibers in direction L or perpendicular to the fibers: directions R and T. The thermal conductivity of wood is affected by various factors. High-density wood conducts heat better than low-density wood due to the smaller proportion of porous space [15]. The low thermal conductivity of wood compared to that of other materials gives wood the image of a warm and pleasant material, with great value as an insulating material. The thermal conductivity values of wood and its derivatives are significantly lower than those of most construction materials used in structures [16].

2.1.4. Thermal Effusivity

The thermal effusivity of a material characterizes its ability to exchange thermal energy with its environment over time and is expressed in J/kg·K [17]. It is proportional to the thermal conductivity λ and the material's inertia, more precisely to its square root. Emissivity describes the speed at which a material absorbs or releases heat and is given by the following formula [18]:

$$E=\sqrt{\rho c_p \lambda} \tag{4}$$

where: λ is the thermal conductivity of the material in W/mK; ρ the density of the material in kg/m^3; c_p the specific heat capacity of the material in J/kg·K.

2.1.5. Operating Principle of the FP2C Machine

The FP2C machine [19] is an easily portable device for instantaneous measurement of the thermal conductivity and effusivity of solid materials (bricks, rocks, building insulation, beams, gels…). This device allows for non-destructive testing of materials on industrial production lines, insulation characterization, and the metrology of thermophysical properties. The sectors of application are construction, ceramics, cosmetics, packaging, food products, and petroleum products.

2.1.6. Measurement Technique of the FP2C Device

The device combines two techniques for identifying the thermal characteristics of materials: the wire, plane, and ring techniques, which rely on the use of shock probes. The hot wire technique is a quasi-steady state method for measuring the thermal conductivity of insulating materials (thermal conductivity up to 5 W/mK), the hot plate technique, which is optional, is the transient method for estimating thermal effusivity, and the hot ring technique, which is also optional, is the transient method for estimating thermal diffusivity.

2.2. Methods

2.2.1. Measurement Principle of the FP2C Device

These techniques rely on the use of shock probes for **Photo 2**. Their principle is to locally produce a slight thermal heating of the material: a few degrees above the ambient temperature, and to measure this temperature increase over time: a duration of a few minutes. Through a mathematical processing of this signal integrated into the provided software, the identification of the thermal parameter is carried out.

The device consists of the following components:

- A power supply and signal conditioning box;

- A power cable, a USB cord for the case/PC connection;
- A hot wire probe;
- An optional 50 × 50 mm^2 hot plate probe;
- An optional hot ring probe;
- A hot needle probe (optional;
- A hot probe (optional;
- A license for the software for managing and calculating equivalent thermal conductivity using the wire method;
- A software license for calculating thermal effusivity (optional;
- A thermal diffusivity software license (optional), a PC (optional), minimum configuration Windows 7, 8, or 10;
- 1 GB of disk space, 2 GB of RAM, one free USB port.

Photo 2. Thermal characterization measurement device.

2.2.2. Determination of Thermal Conductivity

1) Principle of the hot wire probe

This method allows inserting the two samples between the probe, selecting the power source, the time, and the correlation coefficient, and starting a thermal test by stabilizing the temperature with the stab push button for 30 s to 1 minute. Once the temperature stabilization is complete, we proceed to the test by pressing the run button and waiting according to the chosen time and the different indicator light colors. Depending on the results obtained, we proceed to the recording of the data by the machine and the test curve for **Photo 3**.

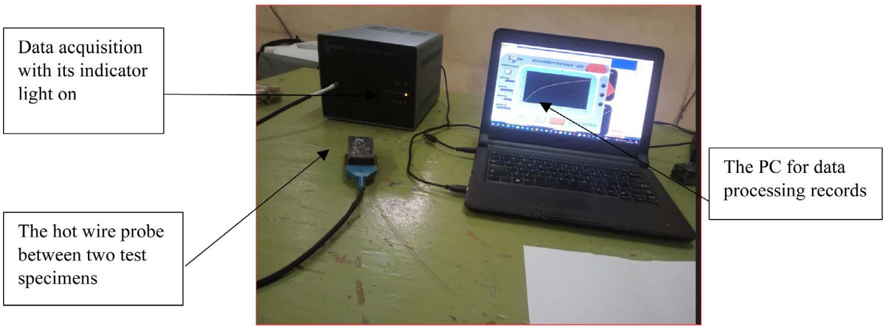

Photo 3. Conducting the thermal conductivity test on the samples.

2) Practical implementation of the measurement

The experimental setup of the hot plate type shown in **Photo 4** was used for the conductivity and thermal effusivity tests of our samples.

Photo 4. Experimental thermal testing device.

3. Results and Discussion

The analysis of this curve in **Figures 1-4** allows us to observe the evolution of thermal conductivity as a function of mass fractions in the different samples. This curve from **Figures 1-4** of the hot wire method has no relation to the determination of thermal conductivity but allows us to see the trend of conductivity evolution in the different samples as a function of mass fraction. Comparisons will be made to see the samples that conduct heat poorly. The results we have presented are the averages of the thermal tests on three samples per mass fraction: 10%; 15%; and 20% in fibers and residues of Borassus wood.

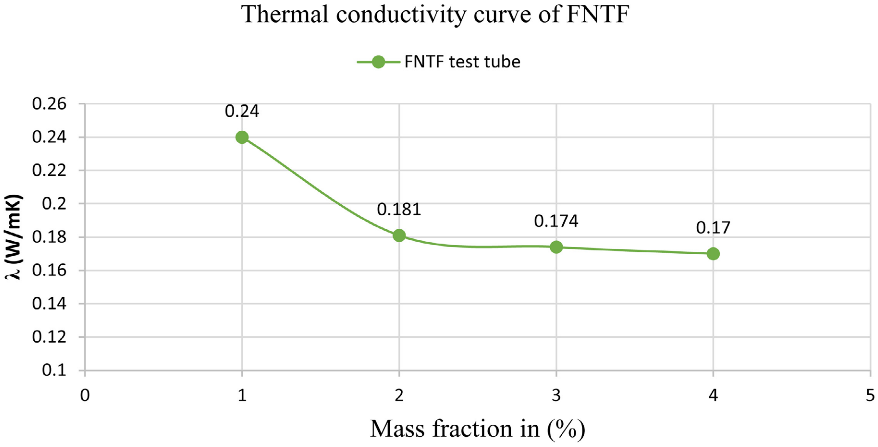

Figure 1. Thermal conductivity curve of FNTF.

The thermal conductivities of the samples of Borassus wood residues and fibers decrease as the mass fractions of powder or fibers increase.

Two opposing behaviors are observed: on the one hand, the introduction of Borassus female wood powder (FNTF) from **Table 1** into a polypropylene matrix

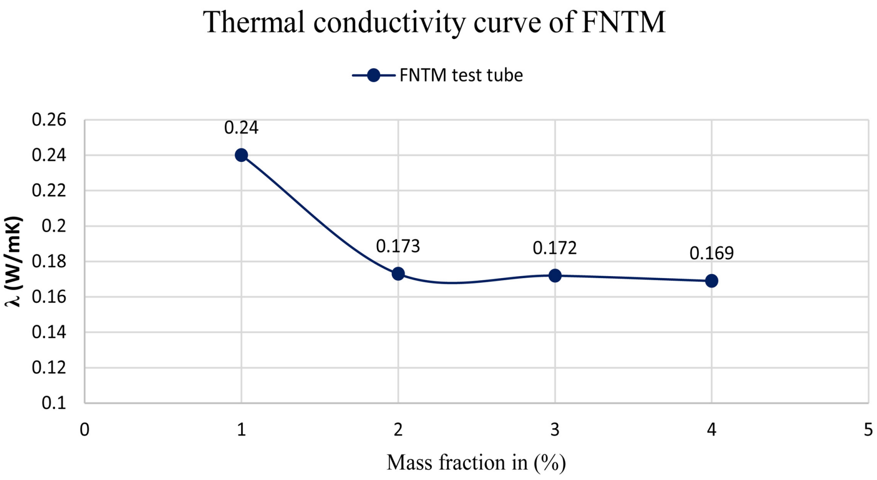

Figure 2. Thermal conductivity curve of FNTM.

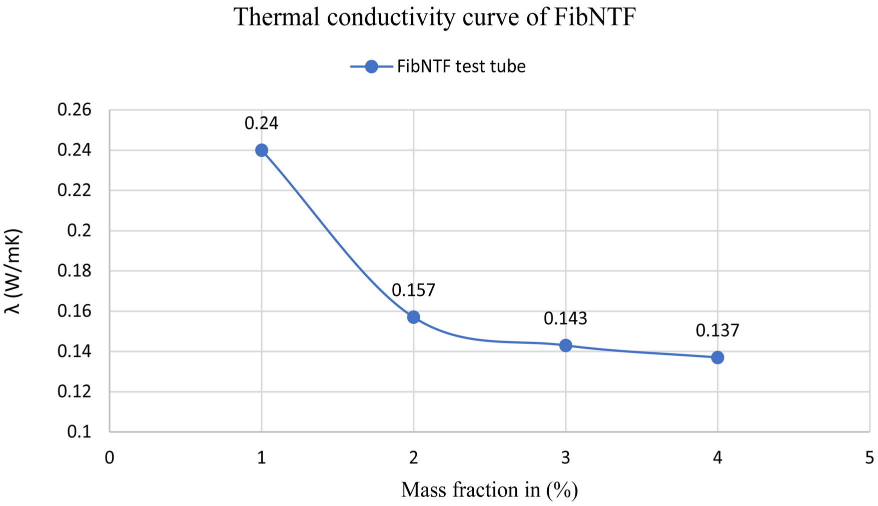

Figure 3. Thermal conductivity curve of FibNTF.

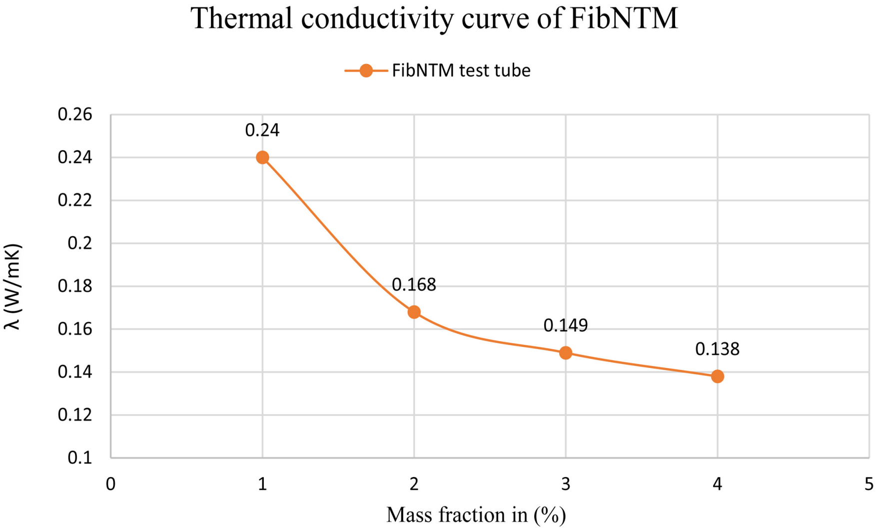

Figure 4. Thermal conductivity curve of Fints.

Table 1. Values of thermal conductivity of FNTF samples.

Designation of specimens	$\lambda(\mathrm{W/mK})$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FNTF at 10%	0.181	0.999	0.20	38.2
FNTF at 15%	0.174			39.2
FNTF at 20%	0.170			37.5

induces a decrease in thermal conductivity as the mass fraction concentration of the wood powder increases., on the other hand, the use of Borassus male wood powder (FNTM) in a polypropylene matrix allows for an observation of a decrease in the thermal conductivity value from 0.169 to 0.171 (W/mK) from Table 2. In the same way that the increase in fibers in a polypropylene matrix increases thermal conductivity, see Table 3 and Table 4. It seems that the use of Borassus wood powder in the polypropylene matrix decreases its conductivity more than that of pure polypropylene.

Table 2. Values of thermal conductivities of FNTM samples.

Designation of specimens	$\lambda(\mathrm{W/mK})$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FNTM at 10%	0.173	0.999	0.20	40.5
FNTM at 15%	0.172			46.03
FNTM at 20%	0.169			43.5

Table 3. Values of thermal conductivity of FibNTF specimens.

Designation of specimens	$\lambda(\mathrm{W/mK})$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FibNTF at 10%	0.157	0.999	0.20	39.3
FibNTF at 15%	0.143			41.16
FibNTF at 20%	0.137			41.5

Table 4. Values of thermal conductivity of FibNTM specimens.

Designation of specimens	$\lambda(\mathrm{W/mK})$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FibNTM at 10%	0.168	0.999	0.20	39.75
FibNTM at 15%	0.149			44.53
FibNTM at 20%	0.138			42.95

The results of the thermophysical characterization of composites including Borassus wood fibers from Chad and their use as an inclusion in a polymer matrix show a decrease in thermal conductivity as the amount of fibers or powders increases: these results are consistent with those of [20].

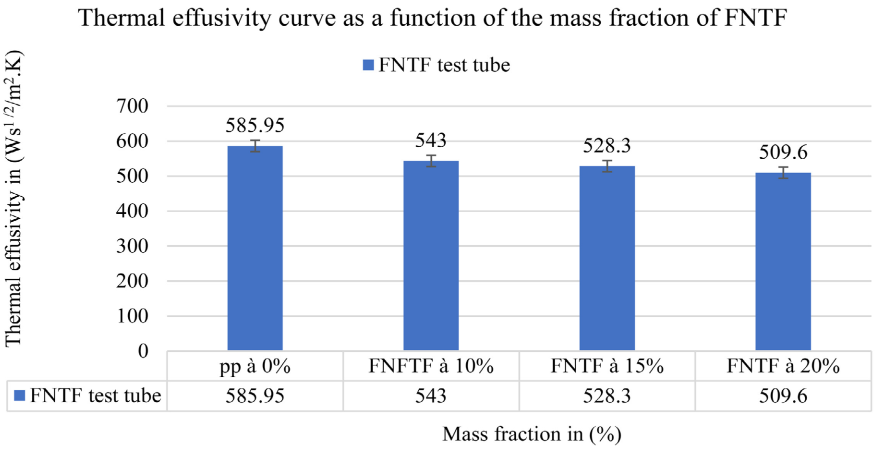

Figure 5. Evolution of thermal effusivity as a function of mass fraction of (10%, 15%, and 20%) of FNTF.

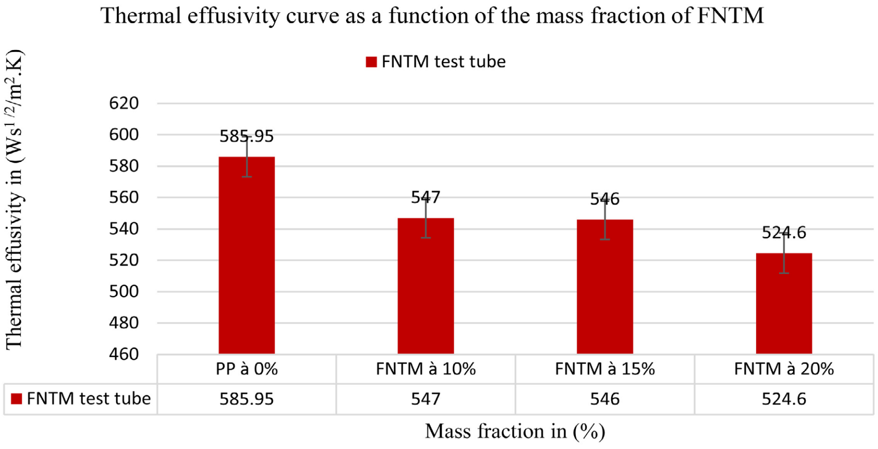

Figure 6. Evolution of thermal effusivity as a function of mass fraction of (10%, 15%, and 20%) of FNTM.

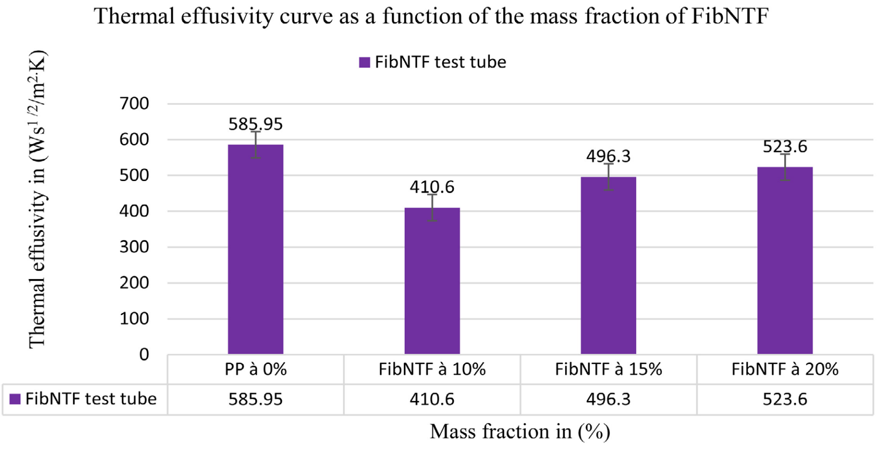

Figure 7. Evolution of thermal effusivity as a function of mass fraction of (10%, 15%, and 20%) of FibNTF.

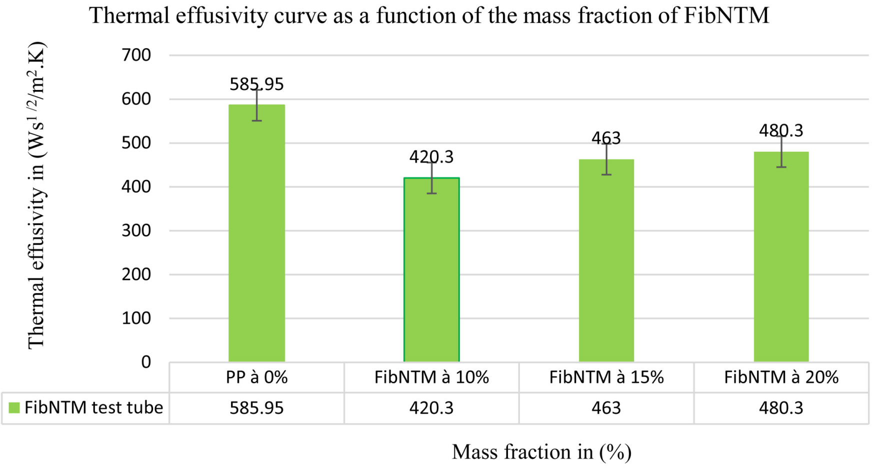

Figure 8. Evolution of thermal effusivity as a function of mass fraction of (10%, 15%, and 20%) of FibNTM.

We observe in **Figure 5** and **Figure 6** a decrease in the thermal effusivity of the samples as the mass fraction of the powder from male or female Borassus wood increases. This decrease is due to the compaction pressure and also to the presence of pores in the samples. On the other hand, we observe in **Figure 7** and **Figure 8** an increase in the thermal effusivity of the specimens as the mass fraction of male or female fibers increases. This increase is sometimes due to the distribution and cohesion of the fibers in the polymer matrix at the time of specimen fabrication.

Table 5. Values of thermal effusivity of FNTF specimens.

Designation of specimens	$B\left(Ws^{1/2}/m^2K\right)$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FNFTF at 10%	543			37.2
FNTF at 15%	528.3	0.999	2.5	37.3
FNTF at 20%	509.6			38.08

Table 6. Values of thermal effusivity of FNTM specimens.

Designation of specimens	$B\left(Ws^{1/2}/m^2K\right)$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FNFTM at 10%	547			42.91
FNTM at 15%	546	0.999	2.5	41.16
FNTM at 20%	524.6			36.16

We also observe two opposing behaviors: on one hand, the introduction of Borassus female wood powder (FNTF) (**Table 5**) into a polypropylene matrix induces a decrease in thermal effusivity as the mass fraction concentration of the wood powder (flour) increases. On the other hand, the use of male Borassus wood powder (FNTM) (**Table 6**) in a polypropylene matrix allows for a decrease in the

Table 7. Values of thermal effusivity of FNTM specimens.

Designation of specimens	$B\left(\text{Ws}^{1/2}/\text{m}^2\text{K}\right)$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FibNTF at 10%	410.6	0.999	2.5	38.6
FibNTF at 15%	496.30			37.93
FibNTF at 20%	523.6			36.83

Table 8. Values of thermal effusivity of FibNTM specimens.

Designation of specimens	$B\left(\text{Ws}^{1/2}/\text{m}^2\text{K}\right)$	Correlation coefficient	Power supply in (W)	Temperature in (˚C)
FibNTM at 10%	420.3	0.999	2.5	38.83
FibNTM at 15%	483			38.6
FibNTM at 20%	480.3			36.83

thermal effusivity value from 547 to 524.6 ($\text{Ws}^{1/2}/\text{m}^2\text{K}$) compared to that of pure polypropylene, which is 585.95 ($\text{Ws}^{1/2}/\text{m}^2\text{K}$). Similarly, the increase in female or male fibers in a polypropylene matrix increases thermal effusivity (**Table 7** and **Table 8**). It seems that the powder from Borassus wood in the polypropylene matrix is more insulating: these results are consistent with those of [21].

The results of the thermophysical characterization of composites including Borassus wood fibers from Chad and their use as an inclusion in a polymer matrix show a decrease in the thermal effusivity of the female and male powder and an increase in thermal effusivity as the mass fraction of the fibers increases.

4. Conclusion

This work aimed at the thermophysical characterization of the residues and fibers of Borassus wood from Chad. According to our results, the residues and fibers of Borassus wood are very good insulators in thermal conductivity and thermal effusivity. However, their appropriate use as composite construction materials for thermal insulation requires mastery of their thermal properties. The fibers and residues of Borassus wood were first agglomerated with the polymer matrix for their experimental characterization of thermal properties. After producing the samples with different mass fractions of Borassus fibers and residues, we proceeded to determine the thermal conductivity and thermal effusivity. This thermal conductivity varies from 0.170 W/mK to 0.182 W/mK for FNTF; from 0.169 W/mK to 0.173 W/mK for FNTM for the powder; from 0.137 W/mK to 0.157 W/mK for FibNTF; from 0.138 W/mK to 0.168 W/mK for FibNTM for the fibers. Compared to other structural materials, the residues and fibers of Borassus can be classified among the best materials for thermal comfort in an atmospheric pressure habitat.

Acknowledgements

I extend my sincere thanks to Mr. MAHAMAT SALEH Abdelkhadir, head of the

Laboratory at the National Institute of Higher Sciences and Techniques of Abéché, to Mr. Djekourbouayon Honoré, and to Ms. Amina Moustapha Hissein, technicians at the IRD Laboratory in N'Djamena.

Author Contributions

Validation: A. Malgnan; E. Ngargueudedjim Kimtangar; Resources: Bassa Bruno, B. Hinpere Wedjou; Supervision, Writing: G.E Ntamack. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this article.

References

[1] Jannat, N., Cullen, J., Abdullah, B., Latif Al-Mufti, R. and Karyono, K. (2022) Thermophysical Properties of Sawdust and Coconut Coir Dust Incorporated Unfired Clay Blocks. *Construction Materials*, **2**, 234-257. https://doi.org/10.3390/constrmater2040016

[2] Adeoti, A.Z.-K., Kpatenon, M.J., Salako, K.V., Ouedraogo, A., Latreille, M., Tollon, C., Zekraoui, L., Mariac, C., Santoni, S. and Beulé, T. (2021) Diversité génétique et histoire évolutive de Borassus aethiopum Mart., un palmier aux multiples usages.

[3] Aholoukpè, H., Vissoh, V.P., Amadji, G., Deleporte, P., Dubos, B., Nodichao, L., Kakai, R.G., Chotte, J.L. and Balavet, D. (2013) Typologie des plantations villageoises de palmier à huile (*Elaeis guineensis* Jacq.) dans le département du Plateau au Bénin. *International Journal of Biological and Chemical Sciences*, **7**, 978-999. https://www.ajol.info/index.php/ijbcs/article/view/95807 https://doi.org/10.4314/ijbcs.v7i3.8

[4] Gbaguidi, V.S., Gbaguidi, A.G.L., Gibigaye, M., Adjovi, E., Sinsin, B.A. and Amadji, T.A. (2010) Determination experimentale des principales caracteristiques physiques et mecaniques du bois du rônier (*Borassus aethiopum* mart.) d'origine Beninoise. *Journal de La Recherche Scientifique de l Université de Lomé*, **12**, Article 2. https://www.ajol.info/index.php/jrsul/article/view/230584 https://doi.org/10.4314/jrsul.v12i2.68046

[5] Zeiri, H., Hamdaoui, O., Mazioud, A., Ibos, L. and Mhimid, A. (2022) Formulation et caractérisation thermophysique et mécanique d'un mortier renforcé par des fibres naturelles végétales de Posidonia-Oceanica et animales de Plumes de Poulet. Société Française de Thermique.

[6] Ali, A. (2012) Performances thermiques du matériau terre pour un habitat durable des régions arides et semiarides: Cas de Timimoune, Memoire de Master, Universite de Mouloud Mammeri.

[7] Meukam, P. (2004) Valorisation des briques de terre stabilisées en vue de l'isolation thermique de bâtiments. Thèse de Doctorat, Université de Cergy-Pontoise.

[8] Allarabeye, N. (2009) Caractérisation structurale, physico-chimique et mécaniques du rônier. Memoire de Master, Institut Universitaire des Sciences et Techniques D'Abeche (IUSTA).

[9] Maache, M. (2018) Elaboration et caractérisation des composites à renfort en fibres naturelles des plantes sauvages. Ph.D. Thesis, Université du 8 Mai 1945 Guelma d'Algérie.

[10] Ayvazyan, V. (2012) Étude de champs de température séparables avec une double décomposition en valeurs singulières. Quelques applications à la caractérisation des propriétés thermophysiques des matériaux et au contrôle non destructif. Ph.D. Thèse, Université de Bordeaux 1.

[11] Saulnier, F. (2014) Influence de traitements physico-chimiques des renforts sur le comportement mécanique des composites à base de co-produits de bois. Ph.D. Thèse, Université de Blaise Pascal-Clermont II.

[12] Belhous, M., Boumhaout, M., Oukach, S. and Hamdi, H. (2023) Effect of a Material Based on Date Palm Fibers on the Thermal Behavior of a Residential Building in the Atlantic Climate of Morocco. *Sustainability*, **15**, Article 6314. https://www.mdpi.com/2071-1050/15/7/6314 https://doi.org/10.3390/su15076314

[13] Mbairangone S., Ntamack G.E., Tikri B., Akana T.F. and Bobet, O. (2023) Thermal Characteristics of Earth Blocks Stabilized by Rice Husks. *Open Journal of Applied Sciences*, **13**, 1796-1819. https://doi.org/10.4236/ojapps.2023.1310142

[14] Lepetit, A. (2017) Élaboration de matériaux composites à base de filaments de cellulose et de polyéthylène. Ph.D. Thesis, Université du Québec à Trois-Rivières.

[15] Niezgoda, M. (2012) Modélisation du transfert thermique au sein de matériaux poreux multiconstituants. Thèse de doctorat. D'Orléans. Université d'Orléans.

[16] Tchini Tanoh, S. (2011) Mesure des propriétés thermo physiques des matériaux réfractaires par voie solaire. Memoire de Master. Institut International de l'Ingénierie de l'Eau et de l'Environnement du Burkina Fasso (2EI).

[17] Amadji, T.A. (2021) Développement d'un éco-matériau de type sandwich à base de composites de bois et plastiques de recyclage, et d'éléments de Raphia hookeri. Ph.D. Thesis, UAC, Université d'Abomey.

[18] Benaniba, S., Driss, Z., Djendel, M., Raouache, E. and Boubaaya, R. (2020) Thermo-mechanical Characterization of a Bio-Composite Mortar Reinforced with Date Palm Fiber. *Journal of Engineered Fibers and Fabrics*, **15**, 1558925020948234. https://journals.sagepub.com/doi/abs/10.1177/1558925020948234 https://doi.org/10.1177/1558925020948234

[19] Fiche technique des FP2C (2023) Fiche Technique 211116 (Version 21.11.16) Francaise; Traitement Thermique.

[20] Nouemssi, G.A., Ntamack, G.E., Mbozo'O, M.N. and Djeumako, B. (2023) Thermal Properties of Earth Bricks Stabilised with Cement and Sawdust Residue Using the Asymmetrical Hot-Plane Method. *Open Journal of Applied Sciences*, **13**, 1910-1934. https://doi.org/10.4236/ojapps.2023.1311151

[21] Babé, C., Kidmo, D.K., Tom, A., Mvondo, R.R.N., Boum, R.B.E. and Djongyang, N. (2020) Thermomechanical Characterization and Durability of Adobes Reinforced with Millet Waste Fibers (*Sorghum bicolor*). *Case Studies in Construction Materials*, **13**, e00422. https://doi.org/10.1016/j.cscm.2020.e00422