Thermo- physics behaviour of raphia vinifera/ Epoxy woven material: Experimental and theoretical approach

Alfred Kendem Djoumessi (kendjoums@gmail.com)
University of Dschang
Nicodème Rodrigue Sikame Tagne
University of Dschang
Elvis Mbou Tiaya
ENSET, University of Douala
François Gapgue
University of Dschang
Ebernezer Njeugna
ENSET, University of Douala

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Alfred Kendem Djoumessi[1,2,3*] Nicodème Rodrigue Sikame Tagne[1,2,3] Elvis Mbou Tiaya[3] François Gapgue[1,2] Ebernézer Njeugna[3]

[1]*Research Unit for Mechanics and Modeling of Physical Systems- (UR2MSP), University of Dschang, Cameroon*

[2]*Research Unit of Industrial and systems Engineering Environment (URISIE), IUT/FV Bandjoun, University of Dschang, Cameroon*

[3]*Laboratory of Mechanics and Adapted Materials (LAMMA), ENSET, University of Douala, Cameroon*

Correspondence should be addressed to kendjoums@gmail.com

Abstract

This work deals with the analysis of the thermo-physical behavior of the raffia vinifiera/Epoxy bio-composite. The material is elaborated then, the thermal and physical properties are determined experimentally and theoretically. The experimental analysis of the thermal behavior is done by the hot plate method and that of the physical behavior it is done by the measuring the density and the kinetics of absorption which is used to evaluate the rate of absorption and the diffusion of water. The theoretical analysis, on the thermal conductivity used the model of Ning/Chou to homogenize the coefficient of conductivity and the method of finite elements in the software Abaqus C.A.E 6.14 to simulate the heat transfer through the composite; the theoretical determination of the density is done using the equation of Agrawal and Broutman. This work shows that the results obtained in experimental approach corroborate well with the theoretical ones. Moreover, this material presents very interesting characteristics such as a very low thermal conductivity which makes it a good insulating material on the one hand and on the other hand a low density (light and less absorbent material) compared to the wood species used in shipbuilding; thus, it is a suitable material for the construction of the superstructure of floating boats.

Keywords: thermo-physics, raffia vinifiera/Epoxy, experimental, theoretical.

Introduction

Comfort and lightness are the key criteria in the design and manufacture of automobiles today (MUÑOZ SÁNCHEZ, 2014). The low weight of the material used is a key parameter as it helps to reduce fuel consumption (Renjith R, 2018). The problem of the mass to be displaced is more acute in the field of shipbuilding because the consumption of boats is greatly influenced by the light weight, which depends greatly on the mass of the material used (Rubino et al., 2020). In addition to the mass to be moved, shipbuilding in sub-Saharan Africa is still confronted with the problem of interior comfort. Between the high density of wood commonly used and the heat felt inside the boats made of metal, the choice of a light and insulating material is essential for the construction of the interior of the ships. For this reason, several works on the elaboration of composites for the naval construction have been done; such as the hybrid bio-composite containing flax fibers and basalt molded by injection of epoxy resin to manufacture the artifact which is used as door; it has an appreciable specific mass (Fragassa, 2017). The study of the influence of seawater on the properties of bio-composites in the long term shows that it is after 20 years that seawater degrades the properties of the material and that water saturation occurs after one month (Davies, 2016). The study of the thermal behavior of woven composites shows that they have a good thermal stability (Aisyah et al., 2019). In addition, the optimization of the thermal properties of these bio-composites have also been the subject of several works, including the use of the finite element method to determine the strength and conductivity of a composite reinforcement woven in plain weave; it results from this work that the thermal anisotropy, orientation and thermal conductivity of the fiber have a significant impact on the thermal conductivity of the material (Aisyah et al., 2021). Also, Ning/Chou proposed a predictive method for the thermal conductivity of plain weave woven reinforcement composites to optimize them (Wu et al., 2016). Just as the numerical simulation by finite element method (FEM) of heat transfer on plain, twill and satin woven reinforcement composite sheets obtained the same results as in the experimental work (Zheng et al., 2021). In any case, the porous structure of the raffia fiber vinifera, shows that it can be used for the implementation of thermal insulation (Njeugna et al., 2012). Thus, the problem of this work is that of optimizing the weight and thermal comfort of boats. Therefore, the goal of this work is to develop a new material with optimal physical and thermal properties that can be used in the implementation of the interior of floating boats. This work begins with the modeling and simulation of heat transfer by conduction through the composite raffia vinifiera fiber, epoxy resin by the finite element method in Abaqus software. Then by the realization and the physical and thermal characterization of the composite since a mechanical characterization of the material was already made (Djoumessi et al., 2022). Finally, by a comparative study between the theoretical results and those experimental; as well as those of the literature.

II Materials and methods

II.1 Experimental work

The material was processed by the contact molding process, because this type of processing method keeps the voids in the fiber unchanged, which gives the material better thermal insulation (Njeugna et al., 2012). The woven reinforcement was first placed in the mold cut to standard dimensions. The resin was then poured in. The resulting material is shown in Figure 1.

The experimental work aims to determine by tests the physical and thermal properties of the material. It is a question of researching the thermo-physical properties of the material in order to appreciate the possibility of using it as a material for the implementation of the upper parts of floating boats. The physical tests are mainly related to the measurements of density, rate and kinetics of absorption. The thermal tests measure conductivity, diffusivity, effusivity and thermal capacity.

II.1.1 Measurement of physical properties

II.1.1.1 The density and water absorption of the material

The measurement of the density of the material is done in two ways as presented by (Agrawal, 2021), the bulk density (ρ_{ap}), by direct mass weighing and volume calculation, according to ASTMD 792 which specifies the number of sample and experimental conditions.

$$\rho_{ap} = \frac{composite\ mass}{theoritical\ volume\ of\ the\ composite} \qquad \text{Eq.1.}$$

And the actual density (ρ_{real}) of the composite determined by direct measurement of mass and volumes. Here, the composite is weighed and then it is coated with paraffin weighed and immersed in distilled water, contained in a graduated volume. The calculation of the real density is given by the expression,

$$\rho_{real} = \frac{M_c}{V_{en} - \left({M_{en} - M_c}/{\rho_{pa}} \right)} \qquad \text{Eq.2.}$$

With M_c (Mass of the composite), V_{en} (volume of the coated composite), M_en

(Mass of coated composite) ρ_{ap} (Density of paraffin).

The measurement of the absorption rate (τ) of the material is made according to the standard ISO 62: 2008 the expression of the absorption rate from (Tagne et al., 2017) is given by:

$$\tau\ (\%) = \frac{M_f - M_i}{M_i} \times 100 \qquad \text{Eq.3}$$

Where M_f is the mass at saturation and M_i the initial mass. The experimental study consists in the measurement of the water gain of the sample (evolution of the absorption rate according to time).

II.1.1.2 Measurement of the thermal properties of the material

The experimental work of thermal characterization aims to determine the conductivity, the resistance, the diffusivity and the thermal effusivity of the material. The standard used is ISO 8302:1991. The working method is described by (Damfeu et al., 2017), it consists in sending a heat flow in a heating element with a stabilized power supply. A K-type thermocouple connected at one end to a Datalogger (PICOLOG) and at the other end to one of the faces of the heating element is used to measure the temperature at the center of the sample. The data recording is based on the following assumptions:

Heat transfer is assumed to be unidirectional;

The experimental device is initially at room temperature;

The heat loss in the experimental device is negligible;

The contact resistance between the heating element and the insulator is low;

The sample and the polystyrene block are semi-infinite media.

The heat flux exiting the heating element to the sample noted (Φ_{01}) is given by:

$$\begin{pmatrix} \theta_c \\ \Phi_{01} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \rho_h c_h e_h p & 1 \end{pmatrix} \begin{pmatrix} 1 & SR_{chs} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \theta_1 \\ E\sqrt{p}\theta_1 \end{pmatrix} \qquad \text{Eq.4}$$

The heat flow out of the heating element to the polystyrene block (Φ_{02}) is given by:

$$\begin{pmatrix} \theta_c \\ \Phi_{02} \end{pmatrix} = \begin{pmatrix} 1 & SR_{chi} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \theta_2 \\ E_i\sqrt{p}\theta_2 \end{pmatrix} \qquad \text{Eq.5}$$

With E and E_i respectively the thermal effusivities of the sample and the insulator. The unit of thermal effusivity is ($J.m^{-2}.K^{-1}s^{-1/2}$). Combining equations (4 and 5) yields the following equation.

$$\theta_c(z,p) = \frac{\phi_0\, S}{p} \frac{1}{\frac{C_h Sp+(1+C_h pR_{chs}S)ES\sqrt{p}}{1+R_{chs}SE\sqrt{p}}+\frac{E_i S\sqrt{p}}{1+R_{chi}SE_1\sqrt{p}}} \quad \text{Eq.6}$$

The inverse transformation of this function for sufficiently long times

(t→+∞) i.e., in the Laplace domain when (p→0) is written:

$$\Delta T(0, t \rightarrow +\infty) = \phi_0 S\left(\frac{E^2 R_{chs}+E_i^2 R_{chi}}{(E+E_i)^2} - \frac{C_h}{S(E+E_i)^2}\right) + \frac{2\phi_0}{(E+E_i)\sqrt{\pi}}\sqrt{t} \quad \text{Eq.7}$$

The evolution of the temperature at the center of the heating element is a function of the square root of time. The thermal effusivity of the sample can therefore be pre-estimated from the simplified one-dimensional model by calculating between two times t and $t + dt$ the slope α of the experimental curve.

$$\Delta T(0,t) = f(\sqrt{t}) \quad \text{Eq.8}$$

Such that the curve is a straight line in this time interval. Note that the calculation is done on the linear one third of the curve and is defined by the equation

$$\alpha = \frac{T(t+dt)-T(t)}{\sqrt{t+dt}-\sqrt{t}} \quad \text{Eq.9}$$

Note that the slope is defined by the equation

$$\alpha = \frac{2\phi_0}{(E+E_i)\sqrt{\pi}} \quad \text{Eq.10}$$

The thermal effusivity of the sample is given by the relation

$$E = \frac{2\,\phi_0}{\alpha\sqrt{\pi}} - E_i \quad \text{Eq.11}$$

The estimation of the volume heat of the material is done by considering the heat transfer δq passing through the probe during a time interval dt infinitely small corresponds to a heat flux defined by the equation

$$\phi_0 = \frac{\delta q}{dt} \quad \text{Eq.12}$$

Furthermore, this flow creates a temperature rise dT in the probe. The heat transfer δq can be broken down as shown in equation.

$$\phi_0 dt = q_e + q_i + q_s \quad \text{Eq.13}$$

Where q_e is the amount of heat that passes through the sample; q_i is the amount of heat that passes through the insulating block and q_s is the amount of heat that passes through the probe. According to Joule's law, the amount of heat is defined by the relationship.

$$\delta q = mC_p dT \qquad \text{Eq.14}$$

The heat flux dissipated by the probe also causes a rise in temperature of the polystyrene block (insulator) and the material. Taking into account the definition of equation (13), equation (14) is written

$$\phi_0 = \left(\rho C_p e + \rho_i C_{p_i} e_i + \rho_s C_{p_s} e_s\right)\frac{dT}{dt} \qquad \text{Eq.15}$$

Plotting the curve $\Delta T = f(t)$ and exploiting the linear part of the curve, we define the slope of the latter by the relation

$$\gamma = \frac{dT}{dt} = \frac{T(t+dt)-T(t)}{dt} \qquad \text{Eq.16}$$

The volume heat is deduced from relation (15) by relation (16):

$$\rho C_p = \frac{1}{e}\left(\frac{\phi_0}{\gamma} - \left(\rho C_p e\right)_i - \left(\rho C_p e\right)_s\right) \qquad \text{Eq.17}$$

The theoretical temperature of the complete model will be calculated thanks to the inversion by the De Hoog algorithm. The Levenberg-Marquardt algorithm integrated in a Matlab code will allow to estimate on an interval $[t_0;\ t_{max}]$ such that the residual curve is centered around 0 °C, the values of E and ρCp (taking as initial value the pre-estimated values) which minimize the sum of the squared errors between the modeled value of the temperature noted $T_{mod}(t)$ and the experimental obtained value$T_{exp}(t)$. Figure 2 shows below present the experimental material used for heat transfer.

II.2 Theoretical work

The theoretical work consists in the physicochemical and thermal modeling of the material. And to the simulation of the behavior of the model for the various tests carried out finally to determine and optimize theoretically the physicochemical and thermal properties of the composite. The first step was to create the geometric model of the woven fabric; this was done in SolidWorks. The table 1 presents the specificities of the woven reinforcement structure that allowed the creation of the geometry.

The representative elemental volume is created from the actual geometry of the woven fabric. For this reason, factors such as: fiber cross-sectional area [1.049; 1.9 mm^2] (Tagne et al., 2017), fiber spacing, fabric thickness, and fiber cross-sectional area (Sikame Tagne et al., 2014), are assumed known and constant. The measured geometric dimensions of the elementary cell are listed in Table 2.

Knowing the geometrical parameters, the geometrical model of the woven fabric is created from the SolidWorks software and imported into Abaqus. Figure 3 shows below present the woven process.

Following the modeling of the geometry, the physico-chemical properties (density and absorption kinetics), then thermal properties (effective thermal conductivity and thermal resistance) of the fiber-epoxy resin composite are determined.

II.2.1 Density and theoretical absorption kinetics

The theoretical density of the composite material (ρ_t) is determined using the equation of Agrawal and Broutman (Broutman., 1992).

$$\rho_t = \frac{1}{(W_f/\rho_f)+(W_m/\rho_m)} \quad \text{Eq.18}$$

Where W_f is the fiber mass fraction, is the fiber ρ_f density (0.12 to 0.24 g/cm3) (Tagne et al., 2017); W_m is the resin mass fraction and ρ_m (1.1g/cm^3) is the resin density (Cerbu, 2015). Knowing that

$$W_m = 1 - W_f \quad \text{Eq.19}$$

From (Broutman., 1992), we have

$$\rho_t = \frac{1}{(W_f/\rho_f)+((1-W_f)/\rho_m)} \quad \text{Eq.20}$$

The absorption of natural fiber-reinforced polymer composites, often follow the prediction of Fick's law (Ehi & Yahaya, 2016). Where the mass of water absorbed increases linearly with the square root of time, and then gradually slows to an equilibrium plateau.

$$V_t/V_{eq} = (4/h)\,(D/\pi)^{1/2}t^{1/2}. \quad \text{Eq.21}$$

Where h is the thickness of the sample, V_t is the moisture at point t (time), and V_{eq} is the moisture at the equilibrium point. The diffusion coefficient, (D) of the material from Equation Eq.21

$$D = (\frac{\pi}{t})\left(\frac{V_t\, h}{4\, V_{eq}}\right)^2 \qquad \text{Eq.22}$$

Is calculated from the experimental results.

The modified equation of the diffusion in the first case obtained from the Fick theory is given by (Manaila et al., 2021).

$$log\frac{V_t}{V_{eq}} = \log k + n \log t \qquad \text{Eq.23}$$

Where k is the diffusion parameter depending on the adhesion between the fiber and the epoxy n parameter depending on the Fick diffusion model for case I (n=1/2).

$$V_t = \frac{(M_t - M_i)/M_e}{M_i} \times 100 \qquad \text{Eq.24}$$

Where M_t is the mass of the sample at the time considered, M_i is the initial mass (dry) of the sample and M_e is the molecular mass of water (18.0153g/mol).

II.2.2 theoretical thermal conductivity

The thermal conductivity in the composite depends mainly on the heat transfer through the fiber and the fluid according to their respective volume fraction (Baxter 1946). That of the fibers in the woven fabric (V_{ft}) is given by

$$V_{ft} = \frac{\rho}{\rho_0} \qquad \text{Eq.25}$$

Where ρ and ρ_0 are the density of the composite and the fiber, respectively; The density of the composite is calculated using its surface area density and thickness

$$\rho = \frac{\text{surface area density of the } composite}{composite\ thickness} \qquad \text{Eq.26}$$

The average density of Vinifiera raffia fiber is 0.1288 g/cm3 (Tagne et al., 2017).

This modeling work consists of determining the effective thermal conductivity of the equivalent material based on the second predictive model of Ning and Chou which is specific to the plain weave woven reinforcement composite. The representative Elemental Volume used in the Ning and Chou model is shown in Figure 4.

The second model of Ning and Chou used, cuts the reinforcement into several elements linked together in series or in parallel to come out with a 3D equivalent thermal resistance model (Reine, 2014).

The modeling is done under the following assumptions:

- The composite is assumed to be thermally isotropic in a global manner.

- The temperature gradient is taken such that the effect of radiation is negligible

- The fiber is assumed to be thermally isotropic

- The geometrical parameters of the fibers in the warp and weft directions are identical.

The effective thermal conductivity of the Ning and Chou composite is given by:

$$\lambda_{eq} = \frac{\lambda_m}{\left(1+\frac{g}{a}\right)^2}\left[\frac{1}{\frac{h_m}{h}+\left(1-\frac{h_m}{h}\right)\frac{\lambda_m}{\lambda_2}} + \propto \frac{g/a}{\left(1+\frac{h_m}{h}\right)+\left(1-\frac{h_m}{h}\right)\frac{\lambda_m}{\lambda_2}} + \beta \frac{g/a}{\left(1+\frac{h_m}{h}\right)+\left(1-\frac{h_m}{h}\right)\frac{\lambda_m}{\lambda_1}+\left(\frac{g}{a}\right)^2}\right] \quad \text{Eq.27}$$

Where $\frac{h_m}{h}$ is the ratio between the thickness of the matrix layer h_m and the thickness of the woven fabric; it is given by

$$\frac{h_m}{h} = 1 - \frac{v_f}{v_{fp}}\left(1+\frac{g}{a}\right) \quad \text{Eq.28}$$

v_f represents the volume fraction of fibers, v_{fp} the volume fraction of impregnated fibers, for our material $v_f = v_{fp}$, a is the average diameter of the vinifera raffia fiber (1.193 mm) (Tagne et al., 2017), g is the space between two consecutive fibers, λ_m is the thermal conductivity of the epoxy resin value (0.26 w/m.k) (Trigui et al., 2014); $\propto$, β, λ_2, λ_1 are the parameters depending on the type of woven fabric, modeling assumptions, and the type of fiber used. For the taffeta cloth weaves $\propto$ =0 and β=4. Given the modeling assumptions, the radial, transverse and longitudinal conductivities are assumed to be equal. $\lambda_1 = \lambda_2$. The effective thermal conductivity of the raffia vinifiera fiber being unknown, that of Kenaf (0.055 w/m.k) was used because it has a density close to that of raffia (Jesús et al., n.d.). Once the equivalent thermal model of the material is determined, it is created in the software Abaqus CAE 6.14 and the simulation of the thermal test is carried out by the finite element method as done by (Kamaludin et al., 2021) and then the experimental results are compared with those obtained theoretically.

III. Results and discussions

III.1 Physicals properties

III.1.1 density

The density of the samples obtained experimentally is 0.451 ± 10% g/cm^3 for the real density and 0.5 ± 10 % g/cm^3 for the apparent density. Contrary to the direct measurement, the modeling work based on the plot of the equation Eq.20 allows to have the whole of the possible values of the density of the material as a function of the mass rate of reinforcement. The curve of figure 5 presents its different values. The theoretical density is represented by the curve in Figure 5.

The curve shows that the density decreases with the increase of the reinforcement mass rate. The mass reinforcement rate of 25% of fiber used gives a theoretical mass density of 0.49159 g/cm3, this is very close to the experimental value. Thus, the theoretical result corroborates with the experimental result. This density is clearly lower than those of some bio-composites, notably the palm of washingtonia and resin (0.687 g/cm3 to 0.812 g/cm3) (Ferrandez-Garcia et al., 2020) and that of the short hair fibre /Epoxy (Mansour et al., n.d.).

III.1.2 Absorption

Although the epoxy resin is hydrophobic, the fact of mixing it with the raffia fiber vinifiera very absorbent (Sikame Tagne et al., 2014), gives the resulting composite an absorption whose result is presented by figure 6.

After 100 days, the composite absorbs a quantity of water equivalent to an average of 12.61% of its initial mass. This absorption rate can be reduced by improving the processing conditions of the composite.

The analysis of the kinetics of absorption makes it possible to appreciate the evolution of the water absorption by the material with time. This behavior is described in figure 7.

The experimental absorption kinetics curve shows that the composite absorbs water rapidly in the first few days due to the high cellulose content in the raffia fiber and the surface pigs on the composite. This absorption behavior is unique to many composites (Kamaludin et al., 2021).

Compared to the woods used in local shipbuilding presented in Table 3, the elaborated composite shows better physical properties.

The modeling of water diffusion is done according to the Fick model for the parameters corresponding to the specificity of the material, thus n=1/2, the calculation of the diffusion coefficient $D = 2.2481\ 10^{-5}$ m2/day or $2.602\ 10^{-10}$ m^2/s and the constant $K = 1.4495\ 10^{-4}$ at a temperature of 25 °C.

The diffusion kinetics analysis curve based on the modified Fick theory is shown in Figure 8.

This model shows that the material developed has a diffusion and absorption similar to that of many other bio composites made by mixing a vegetable fiber with epoxy resin, such as the hemp epoxy and linen epoxy composites presented by (Gillet et al., 2022).

III.2 Thermal properties

III.2.1 Experimental work

The use of composite as thermal insulation in shipbuilding is based on the determination of certain properties such as: conductivity, effusivity, diffusivity and heat capacity. The evolution of the temperature through the composite plate is presented in figure 9.

The interpolation curve indicates by the estimated time that the temperature variation in hundred seconds is 18 ^{0}C, but the useful time range used for the calculation is (50 to 90 seconds) time range where the interpolation error is minimal (minimal residual). These curves show the evolution of the heat flux through the material per unit time. The experimental values are shown in Table 4. The curves are similar to those of (Osseni et al., 2016) and (Damfeu et al., 2017), which have developed their composite by the same method. The effusivity on the other hand is determined by the evolution of the temperature as a function of the square root of the time, figure 10 is the illustration.

These curves allow the calculation of thermal emissivity based on the square root of time. The calculation area retained is that corresponding to the minimum error (3 to 8 seconds).

All values of thermal properties obtained after calculation are summarized in Table 4.

The results in Table 4 show that this material can be used in construction as thermal insulation, as these values are similar to those of other bio-composites used in construction as insulation (Liu et al., 2012). And very low compared to those used in energy efficient building (Trigui et al., 2014).

III.2.2 Theoretical work

The theoretical result aims to present the prediction of the thermal behavior of the composite, starting from the homogenization model of Ning/Chou for the determination of the thermal conductivity coefficient to the simulation of heat transfer through the material in Abaqus by the finite element method. Shows in figure 11.

The curve of the Ning homogenization model shows us that the range where the thermal conductivity values of the model are close to that of the experimental test is [0.35; 0.275] and the effective range of the gap between the fibers is [1.6; 2.2]. This shows that the actual fiber spacing of the woven fabric used for the material is 2 mm. The average of the solution values of thermal conductivity (0.3125) is used for modeling and simulation of the thermal conductivity test in the Abaqus software. This curve leads to the same result as the one obtained by (Osseni et al., 2016) which shows the decrease of thermal conductivity as a function of the increase of the reinforcement rate.

Finite element modeling in Abaqus CAE

The geometric model is created from a homogeneous part module. For the heat transfer analysis, the specific physical-thermal properties such as specific heat, conductivity, density etc. are implemented in the program. The mesh is made by four tetrahedral linear nodes as shown in the work of (Iqbal et al., 2015). The initial conditions are applied for the whole model and the boundary conditions are applied on one face of the composite as in the experimental work. The faces of the material are considered completely insulated. The two temperature conditions are T1 (initial temperature of the composite) and T2 (boundary temperature imposed on one face of the composite). Figure 12 shows some steps of the material modeling.

The result of the modeling shows that, the heat propagates with difficulty through the material, therefore the temperature remains high on the surface where it is applied but does not cross the material. Figure 13 shows the behavior of the material in front of the imposed temperature and the heat flow.

Figure 13 shows us that the heat transfer through the material is negligible. The heat flux produced is very low. The imposed temperature does not pass through the material. Therefore, as in the experimental work, it can be seen that this material can be used as a thermal insulator because it does not let heat through.

The table 5 shows below gives the comparison of heat transfer according to the model of the furnace

The thermal behavior of this material is close to that of some bio-composite used in the thermal insulation of buildings (Damfeu et al., 2016a) and for this residue plants (peanut shell, Kapok, Rattan...) used as reinforcement for bio-composite (Damfeu et al., 2016b).

Conclusion

This work concerned the elaboration and the thermo-physical characterization of a bio composite which can be used in the construction of the superstructures of floating boats. Thus, the material was developed based on raffia vinifiera fibers woven in plain weave and mixed with epoxy resin. The thermal properties (conductivity, effusivity, diffusivity and heat capacity) were determined experimentally and theoretically; the experimental values are (288.46444(J/m^2Ks^1/2), 230193.612(J/m^3K), 0.326892(W/m k), 1.46E-06(m^2/s)) respectively for the effusivity, heat capacity, conductivity and diffusivity. The theoretical work gives for thermal conductivity (0.3125 W/m.^{0}k). The results of the experimental and theoretical study corroborate with a relative error of 5.58 % on the heat transfer and 4.4 % on the thermal conductivity. The analysis of the experimental physical properties (density (0.451 g/cm^3), absorption rate (12.61%), diffusion coefficient (($D = 2.2481\ 10^{-5}$ m2/days)), also presents a corroboration of value with that of the theoretical work, especially the density (0.49159 g/cm^3) for the theoretical study and (0.451 g/cm^3) for the experimental study that is to say, a relative error of 8.25 %. The thermo-physical results show that the material can be used in the construction of the superstructure of floating boats.

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Authors' contributions

All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this article

Declarations

Competing interests

The authors declare that they have no competing interest

References

Agrawal, S. A. (2021). *Simplified Measurement of Density of Irregular Shaped Composites Material using Archimedes Principle by Mixing Two Fluids Having Different Densities Simplified Measurement of Density of Irregular Shaped Composites Material using Archimedes Principle by Mixing Two Fluids Having Different Densities*. *April*.

Aisyah, H. A., Paridah, M. T., Sapuan, S. M., Khalina, A., Berkalp, O. B., Lee, S. H., Lee, C. H., Nurazzi, N. M., Ramli, N., Wahab, M. S., & Ilyas, R. A. (2019). *Thermal Properties of Woven Kenaf / Carbon Fibre-Reinforced Epoxy Hybrid Composite Panels*. *2019*.

Aisyah, H. A., Tahir, P. M., Sapuan, S. M., & Ilyas, R. A. (2021). *A Comprehensive Review on Advanced Sustainable Woven Natural Fibre Polymer Composites*. *February*. https://doi.org/10.3390/polym13030471

Broutman., A. et. (1992). Analysis and performance of fiber composites (second edition). In *Materials Science and Engineering: A* (Vol. 151, Issue 1). https://doi.org/10.1016/0921-5093(92)90189-8

Cerbu, C. (2015). Mechanical Characterization of the Flax/Epoxy Composite Material. *Procedia Technology*, *19*, 268–275. https://doi.org/10.1016/j.protcy.2015.02.039

Damfeu, J. C., Meukam, P., & Jannot, Y. (2016a). International Journal of Heat and Mass Transfer Modeling and estimation of the thermal properties of clusters aggregates for construction materials : The case of clusters aggregates of lateritic soil , sand and pouzzolan. *International Journal of Heat and Mass Transfer*, *102*, 407–416. https://doi.org/10.1016/j.ijheatmasstransfer.2016.06.044

Damfeu, J. C., Meukam, P., & Jannot, Y. (2016b). Thermochimica Acta Modeling and measuring of the thermal properties of insulating vegetable fibers by the asymmetrical hot plate method and the radial flux method : Kapok , coconut , groundnut shell fiber and rattan. *Thermochimica Acta*, *630*, 64–77. https://doi.org/10.1016/j.tca.2016.02.007

Damfeu, J. C., Meukam, P., Jannot, Y., & Wati, E. (2017). Modelling and experimental determination of thermal properties of local wet building materials. *Energy & Buildings*, *135*, 109–118. https://doi.org/10.1016/j.enbuild.2016.11.022

Davies, P. (2016). Environmental degradation of composites for marine structures: New materials and new applications. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *374*(2071). https://doi.org/10.1098/rsta.2015.0272

Djoumessi, A. K., Nicodème, R., Tagne, S., Stanislas, T. T., Ngapgue, F., & Njeugna, E. (2022). *Optimization of the Young ' s modulus of woven composite material made* *by Raphia vini fi era fi ber / epoxy*.

Ehi, I. P., & Yahaya, L. E. (2016). Kinetic Studies on Water Absorption properties of Cocoa-pod Epoxy Composites. *Iranica Journal of Energy and Environment*, *January*. https://doi.org/10.5829/idosi.ijee.2016.07.01.07

Ferrandez-Garcia, M. T., Ferrandez-Garcia, A., Garcia-Ortuño, T., Ferrandez-Garcia, C. E., & Ferrandez-Villena, M. (2020). Influence of particle size on the properties of boards made from Washingtonia palm rachis with citric acid. *Sustainability (Switzerland)*, *12*(12). https://doi.org/10.3390/SU12124841

Fragassa, C. (2017). *Marine Applications of Natural Fibre-Reinforced Composites : A Manufacturing Case Study Á Hybrid reinforcements Á Manual*. https://doi.org/10.1007/978-3-319-62767-0

Gillet, C., Tamssaouet, F., Hassoune-Rhabbour, B., Tchalla, T., & Nassiet, V. (2022). Parameters Influencing Moisture Diffusion in Epoxy-Based Materials during Hygrothermal Ageing—A Review by Statistical Analysis. *Polymers*, *14*(14), 2832. https://doi.org/10.3390/polym14142832

Iqbal, K., Sun, D., Stylios, G. K., Lim, T., & Corne, D. W. (2015). FE analysis of thermal properties of woven fabric constructed by yarn incorporated with microencapsulated phase change materials. *Fibers and Polymers*, *16*(11), 2497–2503. https://doi.org/10.1007/s12221-015-5607-0

Jesús, V. De, Rocha, G., Fernández, R., & Durán, O. (n.d.). *The mechanical properties of glass fiber reinforcement in vinyl ester resin*.

Kamaludin, N. H. I., Ismail, H., Rusli, A., & Ting, S. S. (2021). Thermal behavior and water absorption kinetics of polylactic acid/chitosan biocomposites. *Iranian Polymer Journal (English Edition)*, *30*(2), 135–147. https://doi.org/10.1007/s13726-020-00879-5

Liu, D. T., Xia, K. F., Yang, R. D., Li, J., & Chen, K. F. (2012). *Manufacturing of a biocomposite with both thermal and acoustic properties*. https://doi.org/10.1177/0021998311414069

Manaila, E., Craciun, G., Ighigeanu, D., & Stelescu, M. D. (2021). Water absorption kinetics in composites degraded by the radiation technique. *Materials*, *14*(16), 1–18. https://doi.org/10.3390/ma14164659

Mansour, A., Fateh, A., Akbar, A., Malidareh, N. R., Particles, D. C., Atif, M., Farid, M. Q., Yang, S., Huang, Q., Selvakumar, K., & Omkumar, M. (n.d.). *Processing and characterization of epoxy composites reinforced with short human hair Processing and characterization of epoxy composites reinforced with short human hair*. https://doi.org/10.1088/1742-6596/755/1/011001

MUÑOZ SÁNCHEZ, R. (2014). *Mechanical Behavior of Hybrid 3D Woven Composites Doctoral Thesis*. 228.

Njeugna, E., Tagne, N. R. S., Drean, J., Fokwa, D., & Harzallah, O. (2012). *Mechanical Characterization of Raffia Fibres from " raphia viniferaa ." 3*(1), 1–17.

Osseni, S. O. G., Apovo, B. D., & Ahouannou, C. (2016). *Caractérisation thermique des mortiers de ciment dopés en fibres de coco par la méthode du plan chaud asymétrique à une mesure de température*. *12*(6), 119–129.

Reine, B. (2014). *Étude et simulation de la conductivité thermique de matériaux composites à matrice organique chargée et renforcée de fibres de carbone PITCH*.

Renjith R. (2018). Literature review on marine applications of composite materials (Review of Literature). *Research Gate*, *24*(August), 35. https://doi.org/10.13140/RG.2.2.31010.73920

Rubino, F., Nisticò, A., Tucci, F., & Carlone, P. (2020). Marine application of fiber reinforced composites: A review. *Journal of Marine Science and Engineering*, *8*(1). https://doi.org/10.3390/JMSE8010026

Sikame Tagne, N. R., Njeugna, E., Fogue, M., Drean, J. Y., Nzeukou, A., & Fokwa, D. (2014). Study of water absorption in raffia vinifera fibres from Bandjoun, Cameroon. *The Scientific World Journal*, *2014*. https://doi.org/10.1155/2014/912380

Tagne, S., Rodrigue, N., Ebénézer, N., Dieunedort, N., Didier, F., Fogue, M., Drean, J., & Harzallah, O. (2017). Investigation of the Physical and Mechanical Properties of Raffia Vinifera Fibers along the Stem Investigation of the Physical and Mechanical Properties of Raffia Vinifera Fibers along the Stem. *Journal of Natural Fibers*, *14*(5), 621–633. https://doi.org/10.1080/15440478.2016.1250025

Trigui, A., Karkri, M., & Boudaya, C. (2014). *Propriétés thermophysiques et comportement thermique des composites avec ou sans changement de phase*. *2*.

Wu, J., Tang, H., Wu, Y., & The, I. (2016). *A PREDICTIVE MODEL OF THERMAL CONDUCTIVITY OF*. 77–82.

Zheng, Z., Zhang, N., & Zhao, X. (2021). *SIMULATION OF HEAT TRANSFER THROUGH WOVEN FABRICS*. 1–9.

Figures

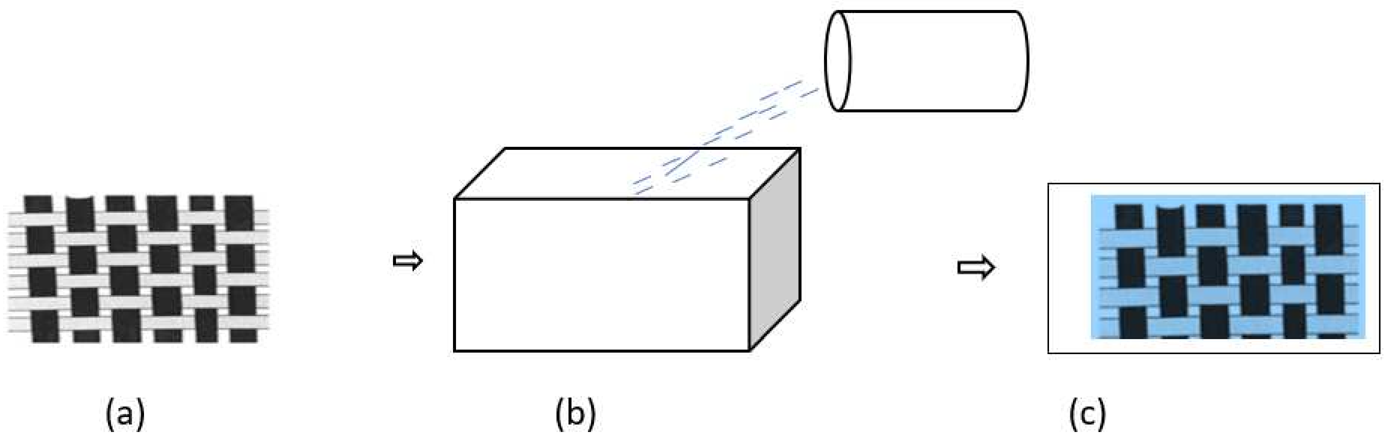


Figure 1

composite development process; woven reinforcement structure (a), composite shaping (b), resulting bio-composite (c).

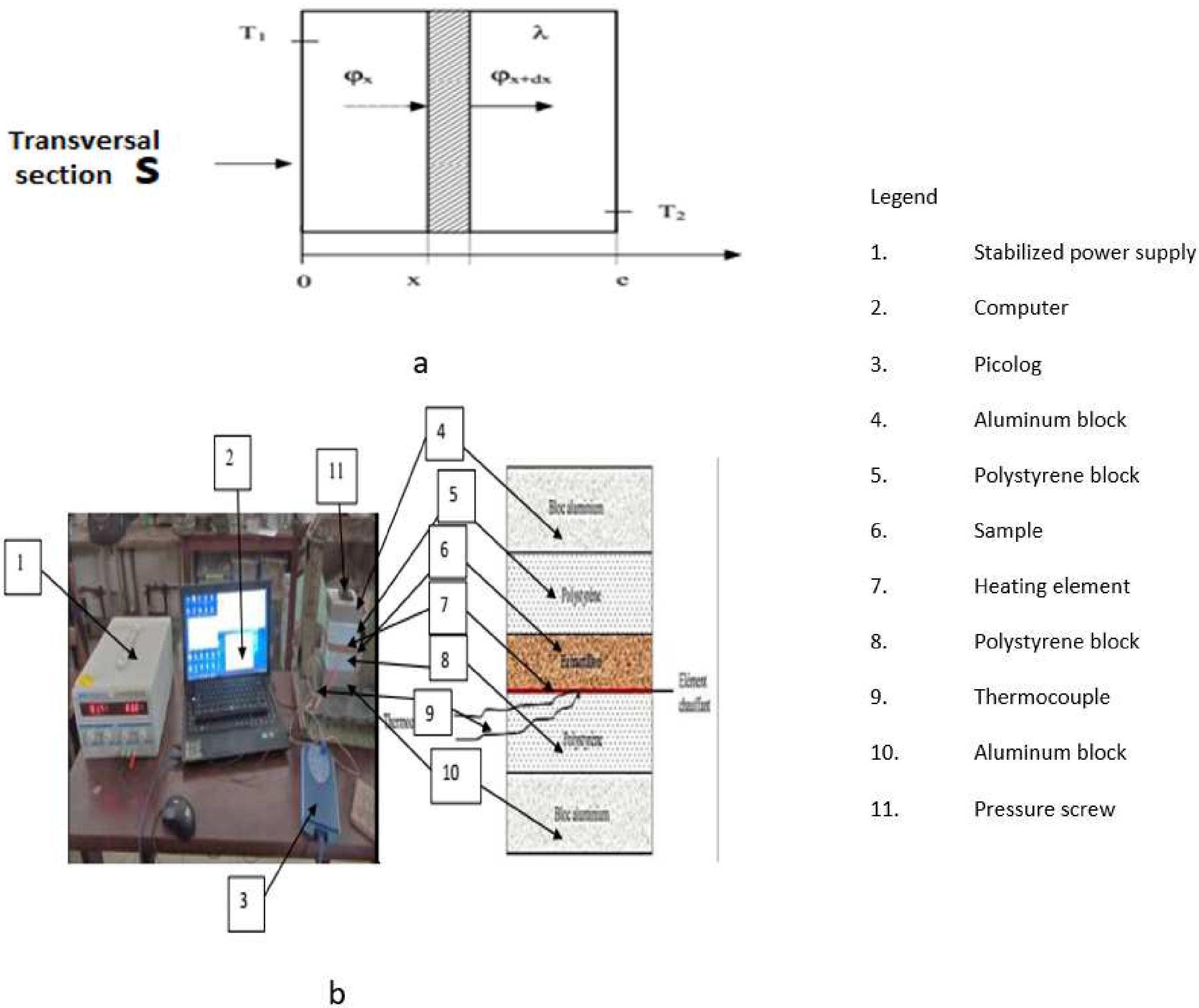


Figure 2

heat transfer: a) schematic diagram of the transfer by conduction, b) equipment used for the acquisition of heat transfer data

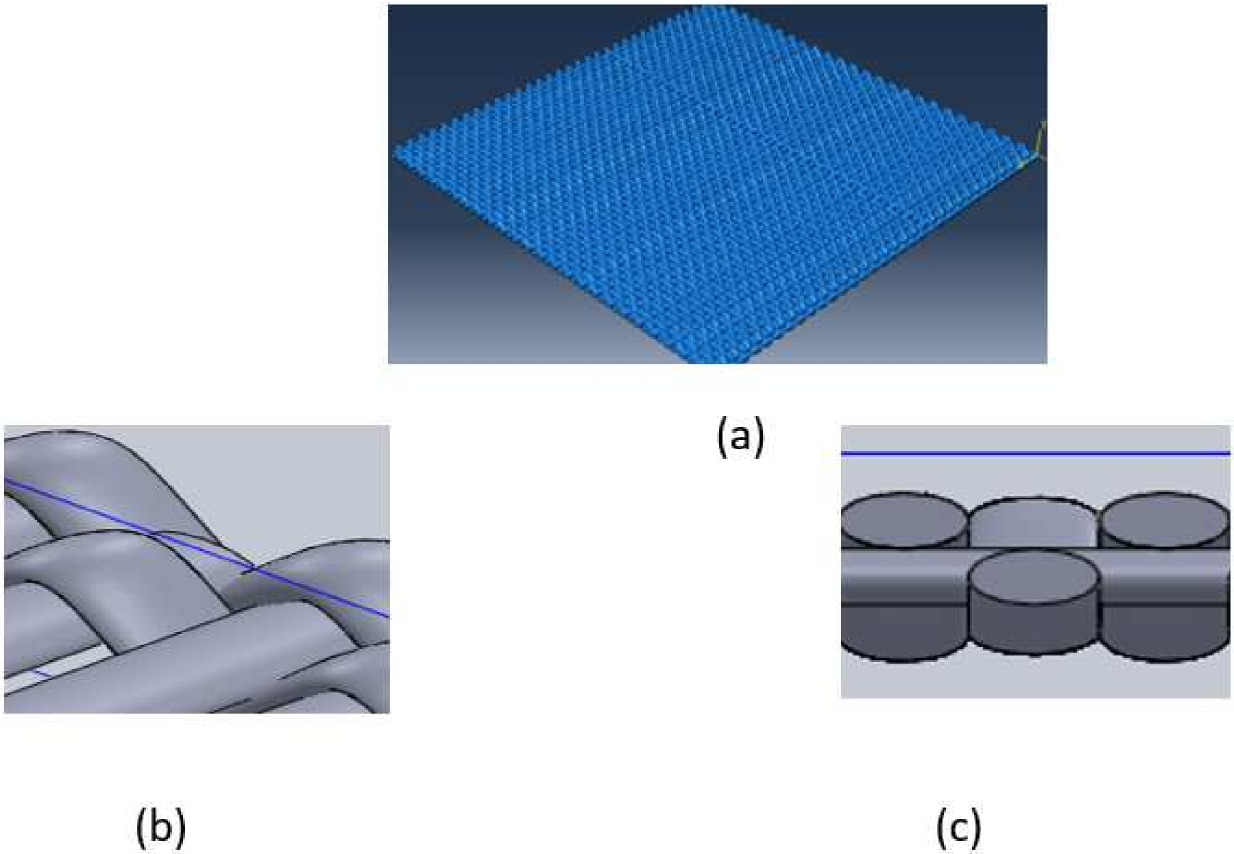


Figure 3

Images of the elementary mesh: (a) overall view of the woven fabric (b) elementary mesh (c) cross sectional view.

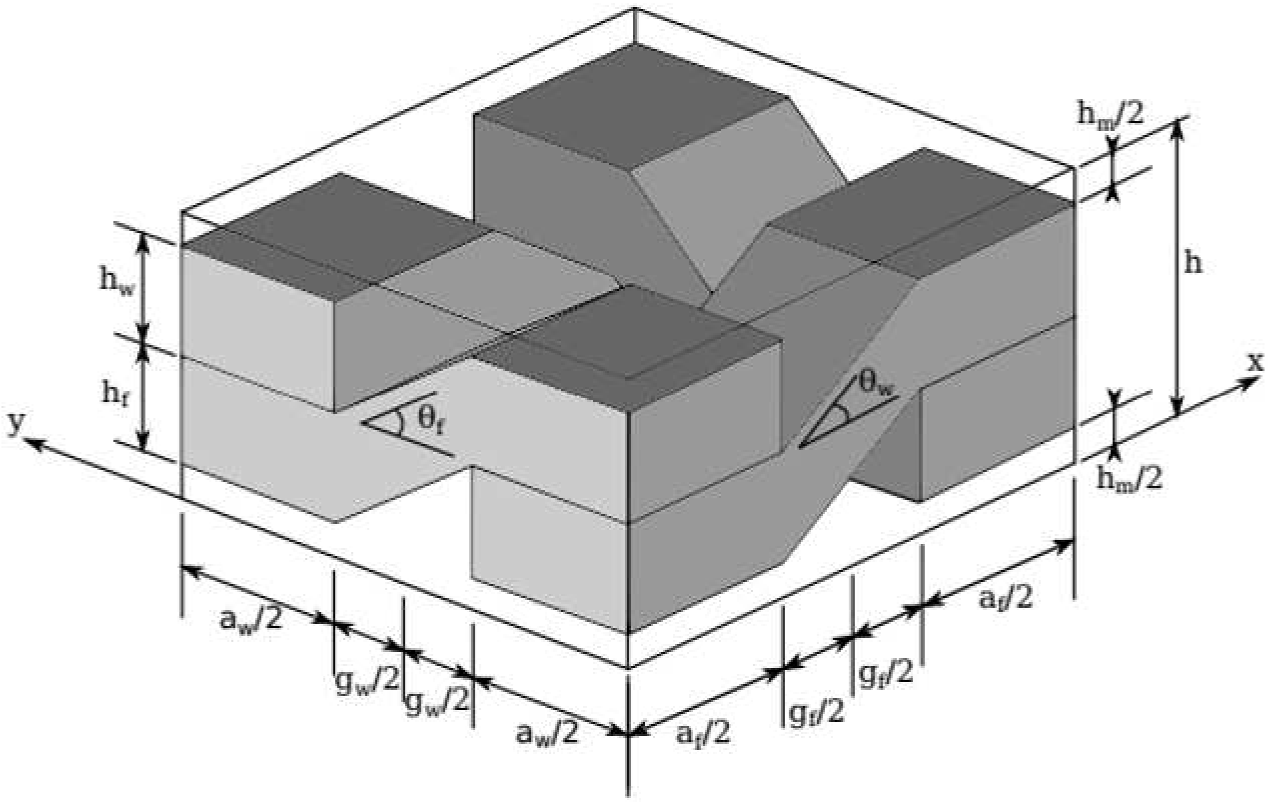


Figure 4

Representative elemental volume (R.E.V.) defined by Ning/Chou [22]

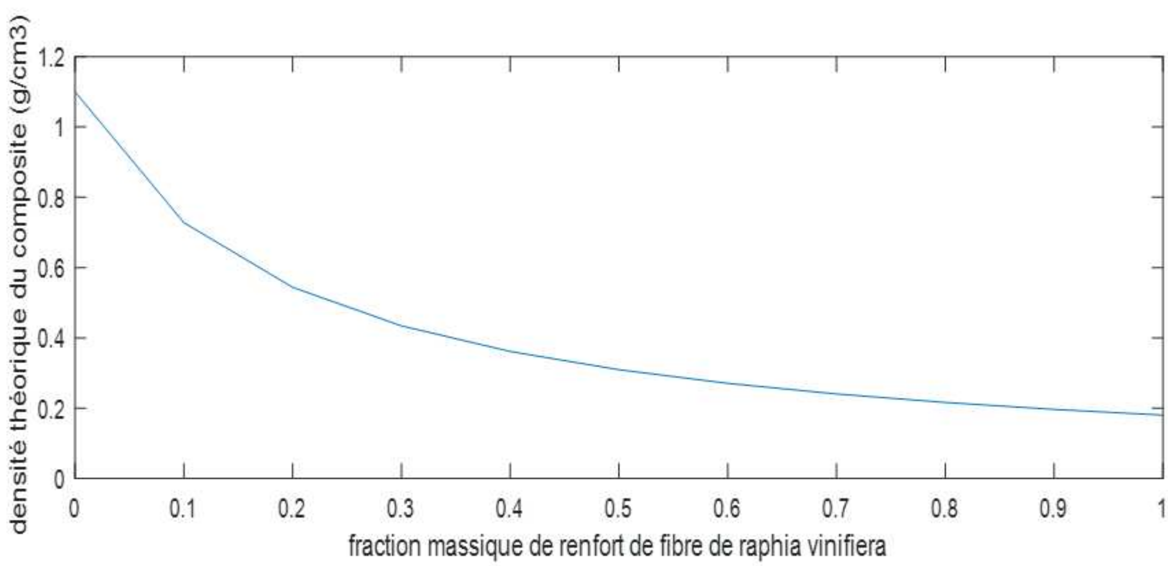


Figure 5

Evolution of the density of the composite as a function of the fiber mass rate.

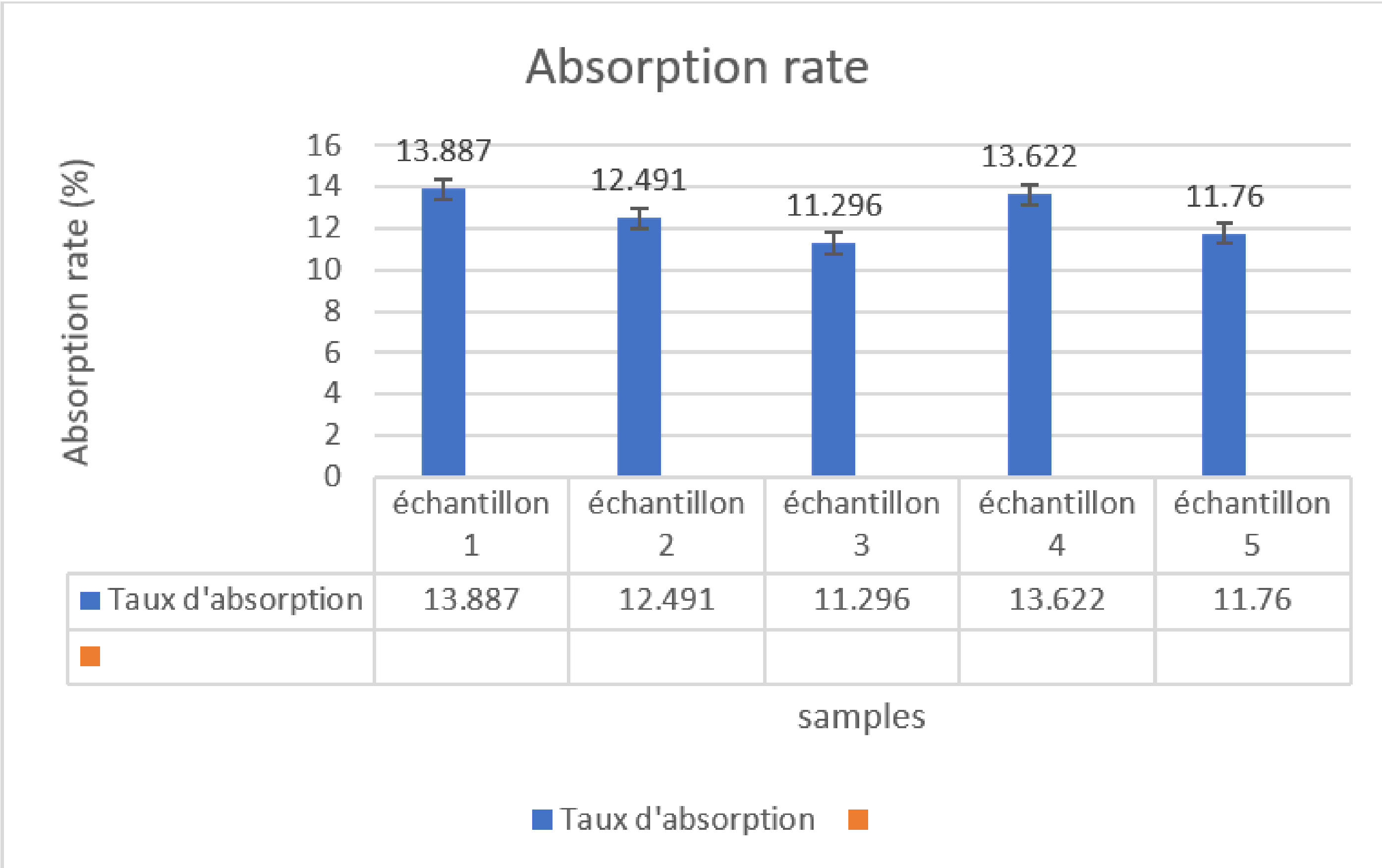


Figure 6

Measurement of the water absorption rate of the composite

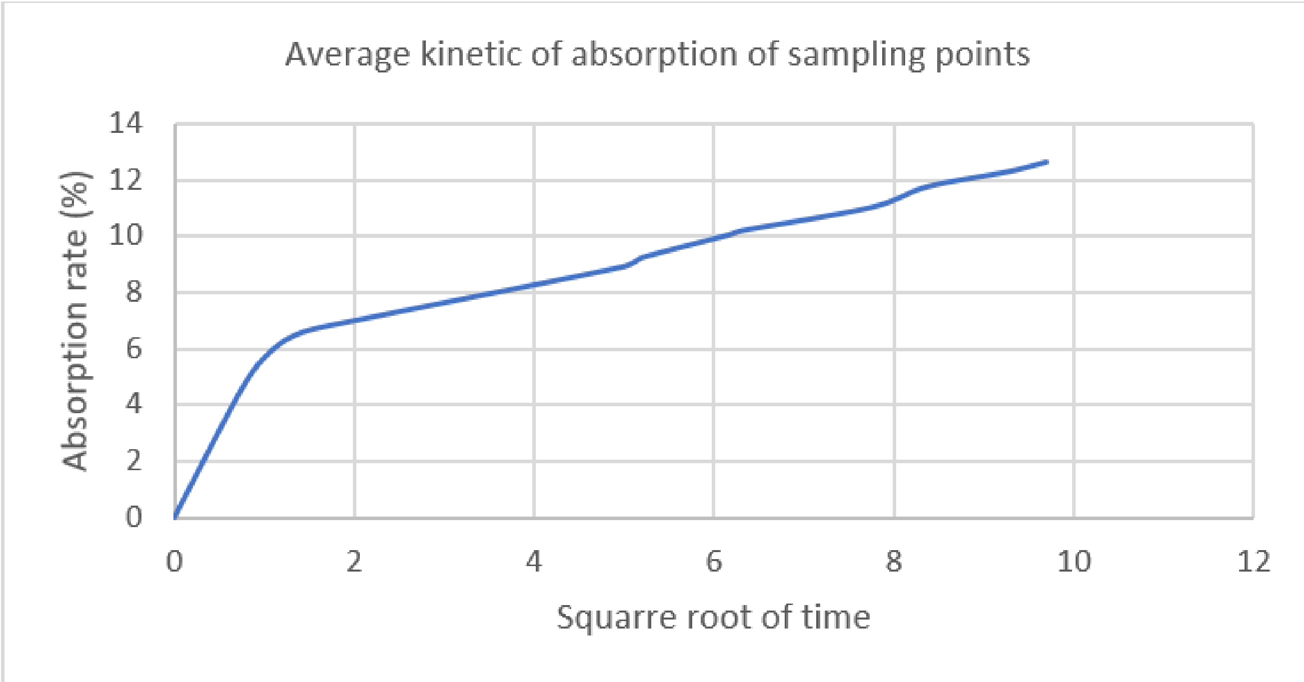


Figure 7

Average kinetic of absorption of sampling points

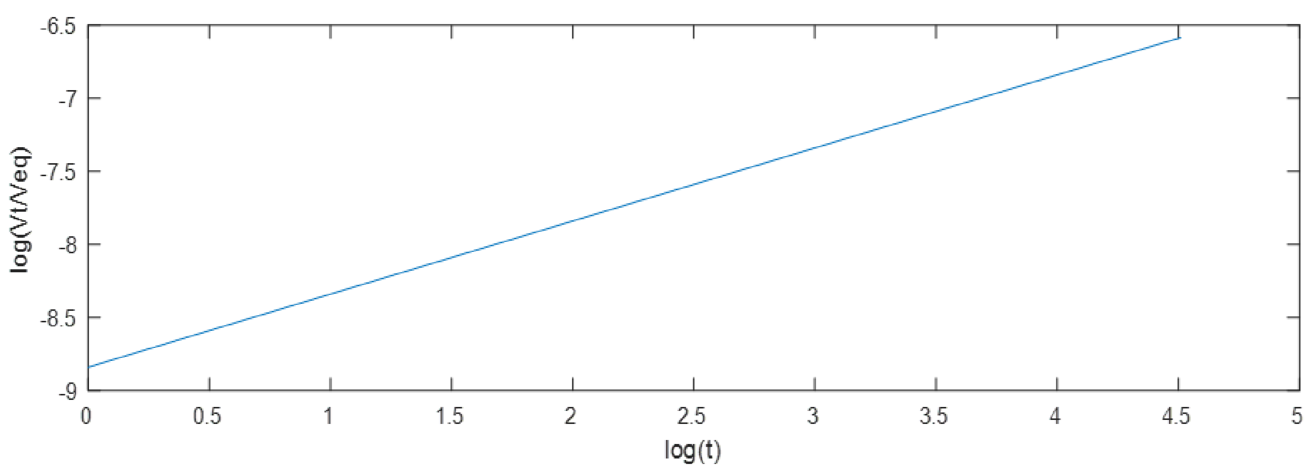


Figure 8

Fick's theory diffusion curve with parameters K and n.

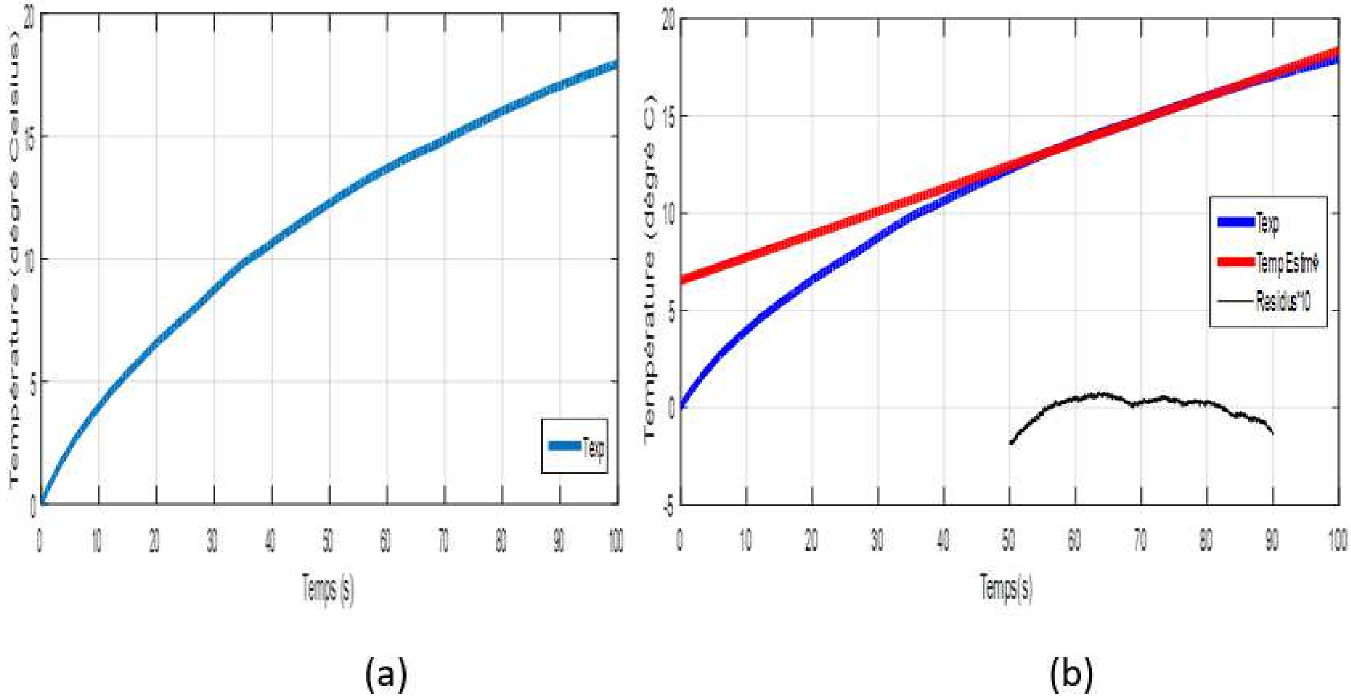


Figure 9

Heat density curves. (a) Temperature versus time, (b) interpolation by estimated time.

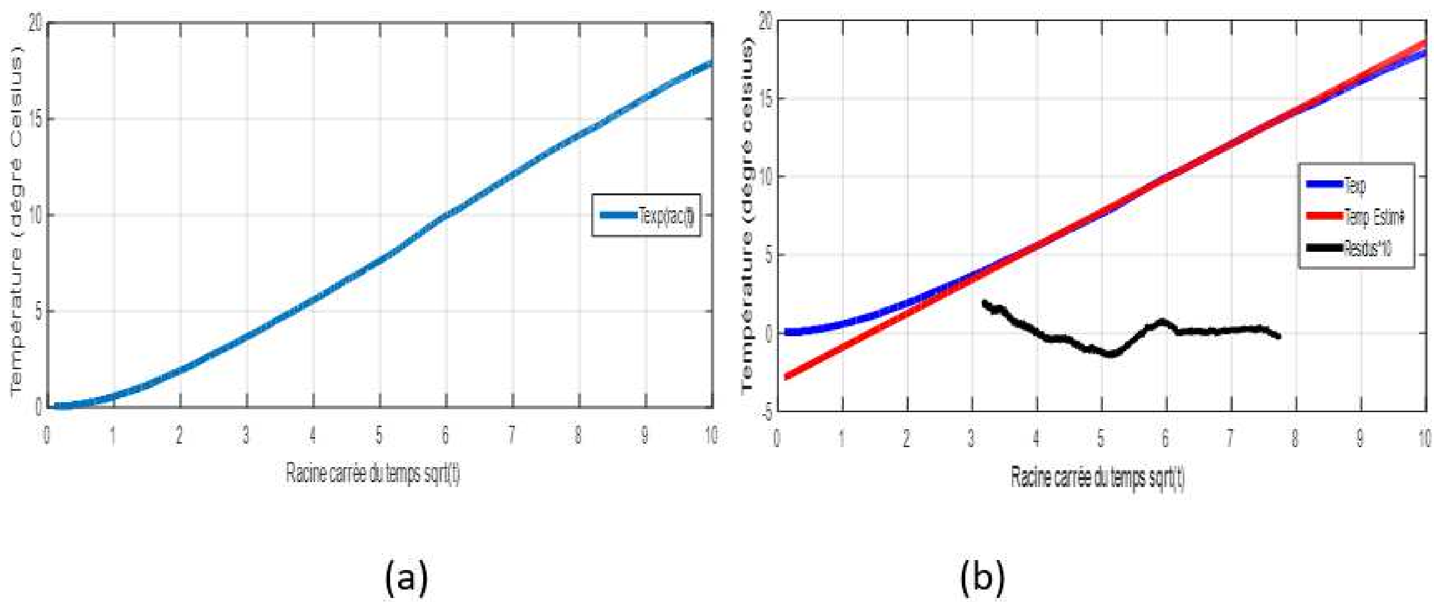


Figure 10

Thermal effectivity curves: (a) Variation of temperature as a function of the square root of time, (b) interpolation according to the estimated time.

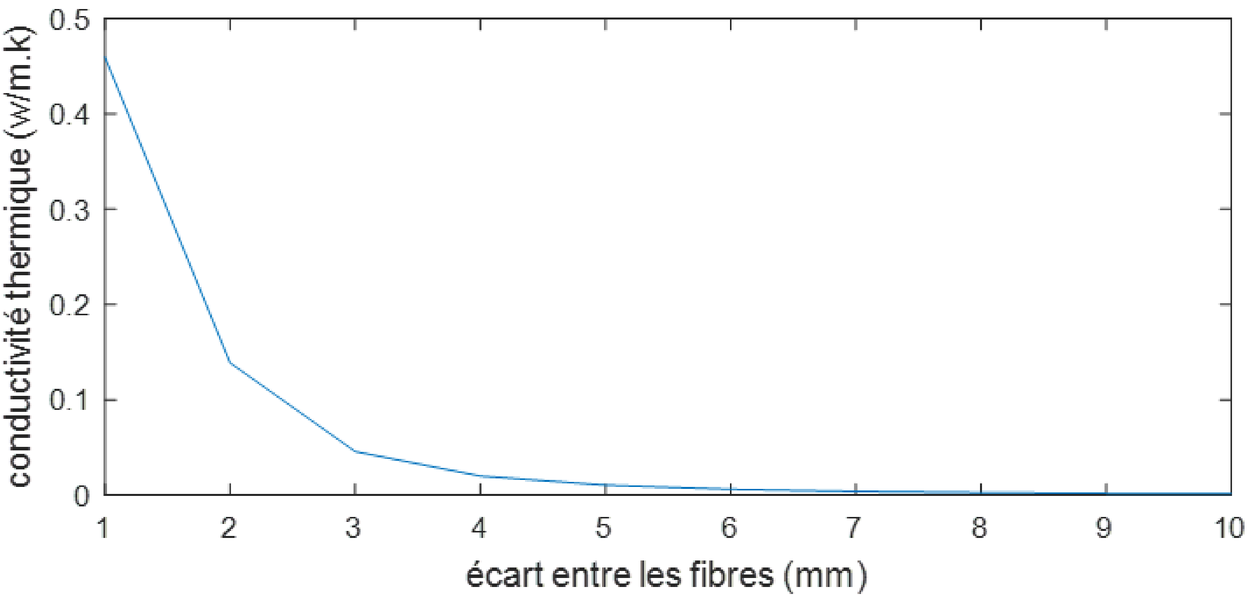


Figure 11

Effective thermal conductivity of the material as a function of the frame count

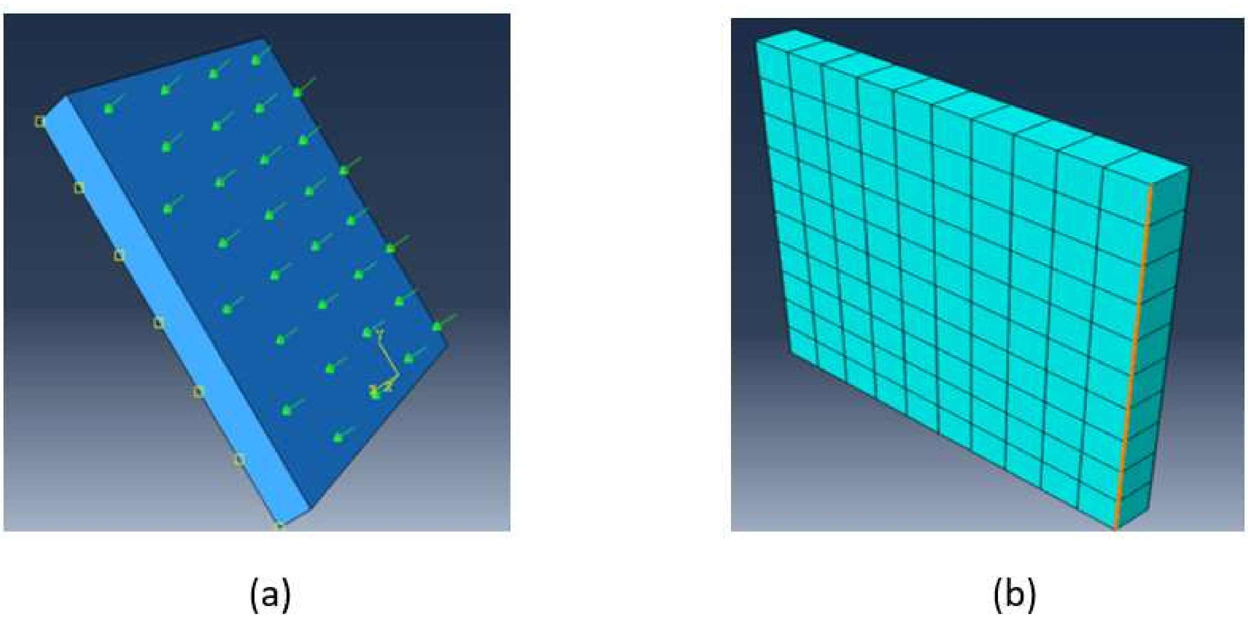
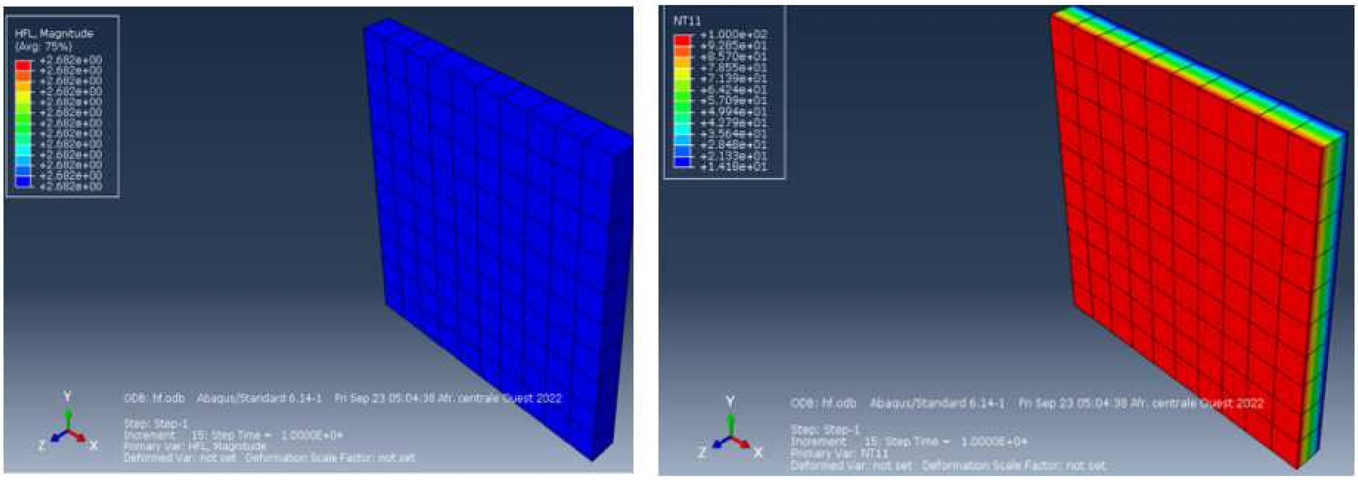


Figure 12

numerical modeling of the material: (a) creation of the boundary conditions, (b) meshing of the material.



(a) (b)

Figure 13

Simulation results of heat transfer through the material: a) heat flux b) nodal temperature at the nodes.

Supplementary Files

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- Tableslists.docx