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RESEARCH ARTICLE

EXPERIMENTAL PHYSICAL AND THERMAL CHARACTERISTICS OF POLYPROPYLENE COMPOSITE MATERIALS FROM BORASSUS WOOD RESIDUES AND FIBERS FROM CHAD

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ABSTRACT

This study focuses on the physical and thermal characterizations of composite materials made from polypropylene with the residues and fibers of Borassus wood from Chad. These properties are experimentally determined in various ways using the hot wire method of the "FP2C" machine, where the hot wire probe is inserted between the two specimens. The values of thermal diffusivity in powdered Borassus wood range from $1.084.10^{-7}$ m²/s to $1.112.10^{-7}$ m²/s for female Borassus wood and from $9.923.10^{-8}$ m²/s to $1.037.10^{-7}$ m²/s for male Borassus wood. For the female and male fibers of Borassus wood from Chad, the thermal diffusivity values range from $6.846.10^{-8}$ m²/s to $1.462.10^{-7}$ m²/s for the female fibers and from $8.254.10^{-8}$ m²/s to $1.597.10^{-7}$ m²/s for the male fibers of the wood.The thermal resistance of Borassus wood powders and fibers ranges from 0.076 to 0.082 for female powders and from 0.076 to 0.090 for male wood. For Borassus wood fibers, the values range from 0.068 m². K /W to 0.105 m². K /W for female fibers and 0.075 m². K /W at 0.084 m² .K /W for the male fibers of Borassus wood. The density values in powdered Borassus wood range from 771,000 kg/m³ to 808,667 kg/m³ for female wood and from 779,000 kg/m³ to 872,667 kg/m³ for male wood.

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INTRODUCTION

The globalization of markets as well as environmental considerations have prompted several academic and private laboratories to undertake work on the development of new composite materials (Lambert, 2003). The main concern of builders is to ensure the longevity of their constructions. Of plant origin, natural fibers and residues represent more than 40 billion dollars per year in the economic sector and a production that approached 35 million tons in 2019 (Touloum et al., 2012). However, composites made from fibers and residues of different types of polymeric matrices constitute an important class of bio-based materials characterized by numerous application possibilities (Lahmar, 2016). It should be noted that wood fibers were the first fibers used as reinforcement in the thermoplastic matrix, offering several advantages due to their good physical and thermal properties, and this new class of wood composites offers interesting opportunities to combine different properties. Generally, the new bio-based composites are formed thru the polymerization of a monomer in the empty pores of wood, fiber, or powder into a solid. The polymer matrix plays the role of distributing the load between the fibers or powders and ensuring their assembly and adhesion (Samah et al., 2013). These materials have become expensive on the market, and there are supply difficulties in some low-income countries. Let's also note the issue related to the manufacturing of these materials, which directly influences their physical and thermal properties. That's why many researchers have focused their work in this field to address or correct these problems.In the context of our study, we are interested in BorassusAethiopum Mart wood, which is an angiosperm spermatophyte plant found in the tropical regions of Sub-Saharan Africa. It is used in construction and public works for various purposes such as building materials and in textiles (Bienvenu, 1989).

MATERIALS AND METHODS

The raw material used for the experiment is Borassus wood, which comes from the palm grove field of Tchoua village, a locality in the central Tandjilé department, about 25 km from Lai, the capital of the Tandjilé province, located between 9'18''36''' East latitude and 16'4''45''' East longitude. Given the importance of the potential in palm groves, the Borassus woods studied are male and female species aged between 30 and 40 years and ranging in height from 11 meters for the male and 9 meters for the female (NetodjiroAllarabeye, 2009).

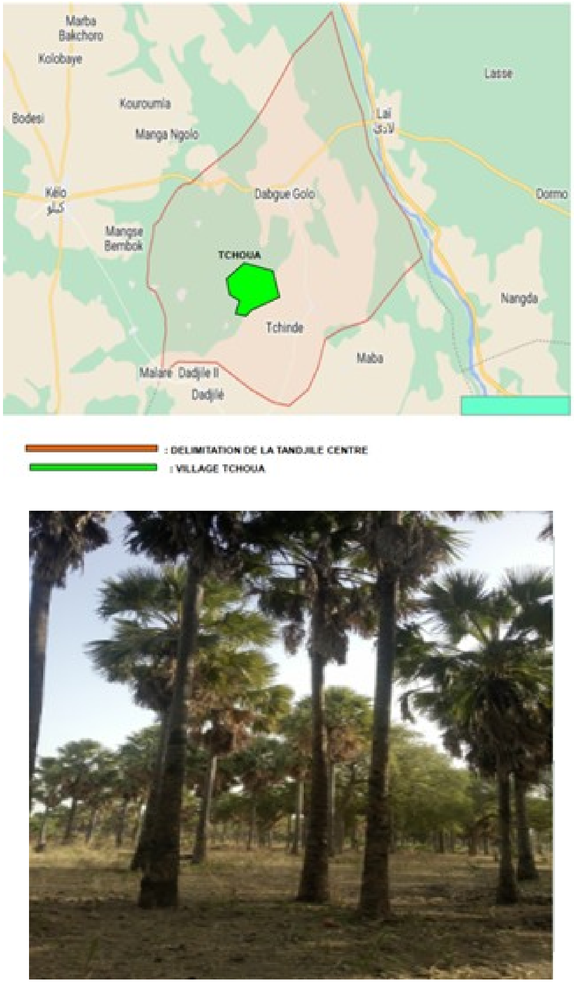

Figure 1. Map of the location of the Borassus wood sampling site in Tchoua Village

The materials used for the formulation of the composites are plant-based fillers in fiber form and the residues of Borassus wood from Chad.

Grinding and Sieving of Residues into Powder: The Borassus residues were ground by an electric machine of the brand RetschGmbh 5667 HAAN GERMANY with rotating blades at a speed of 300 rpm in the laboratory of the Livestock Research Institute for Development in N'Djamena (Maache, 2018).

Figure 2. Electric machine for grinding residues into powder

Modification of Borassus wood fibers and residues: The fibers and residues were immersed in a sodium hydroxide solution at different concentrations ranging from 2.5 to 5% for 24 hours in open air at room temperature in the laboratory. After this treatment, these fibers and residues were washed several times with distilled water. The traces of the sodium hydroxide (NaOH) solution are neutralized by a 5% aqueous solution of acetic acid for 30 minutes at room temperature, then the fibers and residues are rinsed several times with distilled water (Salim, 2017). Finally, the fibers and residues were dried in an oven at 100°C for 24 hours according to the flowchart.

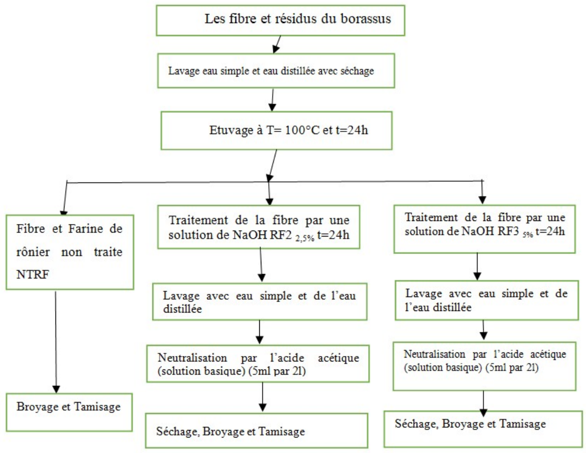

Figure 3. Flowchart of the treatment of Borassus residues and fibers with soda

Figure 4. The fibers and residues of Borassus wood treated with soda

Preparation of composites: The composites based on Borassus wood fibers and powder were prepared in a container by mixing the polypropylene and the powder before placing it on a hot plate for 6 to 8 minutes to melt the polypropylene. After melting, it was spread in a mold and placed under a compaction pressure of 7 bars using an EMERPAC GA4 machine.The shape of the flow depends on the capillarity of the fibers, due to the architecture of the reinforcements, and on the competition between the flow front inside the fibers and the one outside due to the double scale of porosity of the reinforcements. First, the polypropylene resin flows between the fibers and then impregnates the interior of the denser fibers (Lagardere, 2021). On the other hand, for the specimens made from fibers, the following procedure must be followed:- Spread the fibers in the mold; - Melt the PP in a container at a temperature of 160°C; - Pour the sticky PP liquid over the fibers in the mold; - Place the mold under compaction pressure; - Cool the mold thru the water circulation system in a tank; - Proceed with demolding to obtain the manufactured specimens.

Figure 5. Technique for preparing specimens based on PP, residues, and Borassus wood fibers

RESULTS AND DISCUSSION

Influence of the NaOH solution on the fibers and residues of Borassus wood: In order to modify and improve the adhesion between the fibers and the matrix and consequently also enhance the properties of the composites, particularly the mechanical properties,

Table 1. Values of the density of the specimens

Designation	ρ average (kg/m^3)	Standard deviation of density	Density (d)	Standard deviation of Density
FNTF10 %	771,000	36,506	0,771	0,037
FNTF15 %	806,000	25,153	0,795	----------
FNTF20 %	808,667	22,838	0,809	0,023
FNTM10 %	779,000	71,907	0,779	0,072
FNTM15 %	797,333	32,252	0,797	0,032
FNTM20 %	872,667	12,284	0,873	0,012
FibNTF10 %	685,333	35,160	0,685	0,035
FibNTF15 %	750,000	74,135	0,750	0,074
FibNTF20 %	755,333	10,625	0,755	0,011
FibNTM10 %	730,667	64,789	0,731	0,065
FibNTM15 %	802,000	34,409	0,802	0,034
FibNTM20 %	793,333	22,171	0,793	0,022

Table 2. Water absorption of FNT (female and male)

Time (h)	FNTF 10%	FNTF 15%	FNTF 20%	FNTM 10%	FNTM 15%	FNTM 20%
0	0	0	0	0	0	0
2	99,90	121,86	113,61	122,18	127,14	117,71
4	101,21	123,24	115,13	123,43	127,99	118,46
6	101,35	123,33	115,24	123,58	128 ,00	118,87
8	101,72	123,35	115,32	123,72	128,38	118,93
10	101,80	124,50	116,00	124,00	128,99	119,50
12	102,30	125,00	116,50	125,00	129,49	120,00
24	104,00	125,50	117,50	126,50	130,43	122,00

Table 3. Water absorption of FibNT (female and male)

Time (h)	FibNTF 10%	FibNTF 15%	FibNTF 20%	FibNTM 10%	FibNTM 15%	FibNTM 20%
0	0	0	0	0	0	0
2	93,54	87,25	100,2	96,73	100,48	94,70
4	98,93	93,62	104,52	100,37	104,58	100,17
6	99,17	95,28	105,63	102,13	107,88	104,70
8	99,94	96,19	109,47	102,89	111,43	112,27
10	101,29	98,66	112,21	105,60	111,43	112,27
12	103,28	101,16	115,21	108,00	113,50	117,77
24	105,38	103,90	119,21	110,50	115,50	120,27

the fibers and residues were subjected to various chemical treatments (Achouche&Aichouche, 2019). Composites were developed from fibers and residues all previously treated with a sodium hydroxide (NaOH) solution of different concentrations of sodium hydroxide at 2.5% and 5%. The 5% soda concentration has a very significant influence on the fibers and residues of Borassus wood, whereas the 2.5% soda concentration does not greatly affect the fibers and residues of Borassus wood during 24 hours in the open air of IRED (Parre et al., 2020). After these treatments, the residues and fibers of Borassus wood are in good agreement with the aforementioned observations. Indeed, the result shows that the length and size of the fibers and residues decrease with the duration of the soda treatment, thus indicating a degradation of the fibers and residues into small fibers of negligible size (El Boustani, 2016).

Bulk densities: The following table 1 presents the values of the bulk densities, density, and standard deviation of the Borassus residue and fiber specimens from Chad. The densities presented in Table 1 are obtained by measuring the different masses using a precision balance, to the tenth (0.1) of a milligram. The dimensions of the specimens are measured with a caliper. For this purpose, we calculate the volume and then the density of the specimens. The thicknesses of the specimens are not all the same, they vary after demolding. We present the results of the bulk density of the FNTF, FNTM, FibNTF, and FibNTM specimens as a function of the mass fraction of fibers or Borassus powder from Chad, at a moisture content of 12% according to the French standard NF B51-002. The measured values range between 642 and 890 kg/m³, which is consistent with data from other researchers (Guidigo, 2017) and (Abdellah, 2013; Abdessalam, 2012). This trend is observed both for the extruded specimens and those made by the artisanal method. Moreover, the density increases slightly with the mass fraction of fibers and residues: 10%, 15%, and 20%, which is consistent since the matrix has a higher density than that of Borassus fiber. According to the results of figures 6 and 7, we observe that: the density of the specimens increases as the mass fraction of powders or fibers increases. This increase is due to strong pressure that allows for greater compaction of the particles, thereby reducing the air volume in the materials. Indeed, the specimens made from Borassus powders are heavier than those made from fibers. The density of the powder specimens is 872.667 kg/m3 for male Borassus powder and 808.667 kg/m3 for female Borassus powder, while that of the fibers is 793.33 kg/m3 for male fibers and 755.33 kg/m3 for female fibers.

Water absorption: Water absorption is an essential property for characterizing materials based on powder and plant fibers (Do Thi, 2011). In this study, we conduct water absorption experiments according to the literature. The specimens are first dried at 70 °C under vacuum for 24 hours, then cooled in a desiccator and weighed immediately. They are then immersed in distilled water at room temperature. After 2, 4, 6, 8, 10, 12, and 24 hours, a specimen is removed, the surface water is absorbed with a tissue, and the specimen is weighed.

The main water absorption results, the average of two values, of the specimens are presented in the following tables 2 and 3: Figures 8 and 9 show the evolution of the water absorption rate as a function of the mass fraction of Borassus residues and fibers for different immersion durations of the specimens. The amount of water absorbed by the powder specimens remains constant, while that of the wood fiber specimens increases due to their porosity. Composites containing Borassus fibers absorb more water than those with Borassus wood residues. However, several authors report contrary results, indicating that the incorporation of fibers into a polymer matrix reduces water

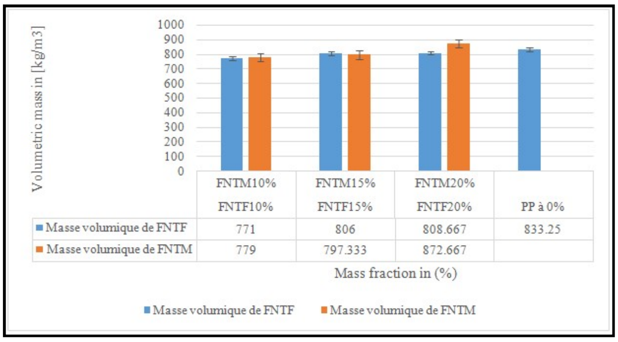

Figure 6.Variation of the density of FNTF and FNTM as a function of the mass fraction

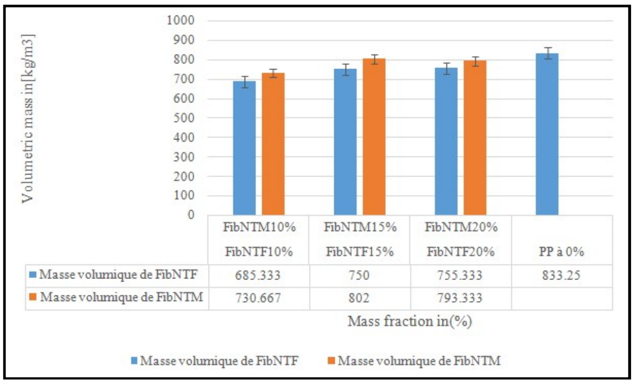

Figure 7. Variation of the density of FibNT (male and female) as a function of the mass fraction

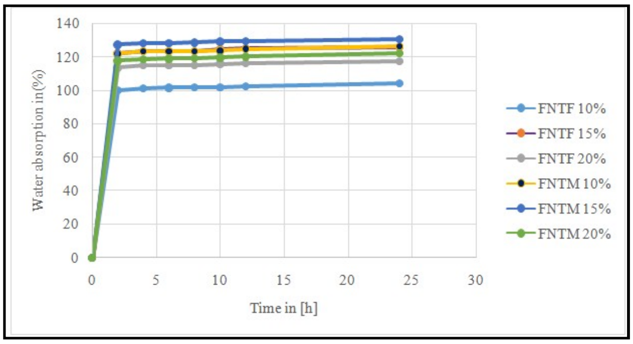

Figure 8. Evolution of water absorption of FNT (female and male) as a function of immersion time

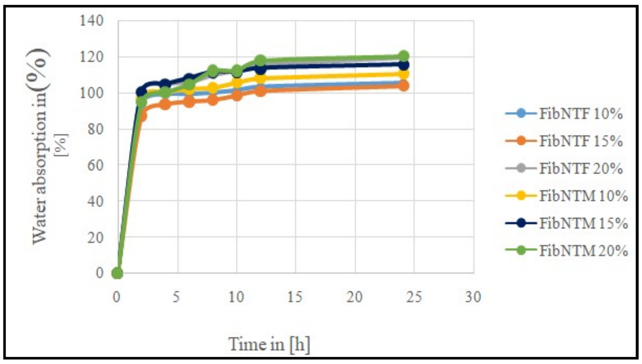

Figure 9. Evolution of water absorption of FibNT (female and male) as a function of immersion time

uptake, despite their hydrophilic nature. They explain this by the fact that the swelling of cellulose by water is less than that of the residues, and that cellulose is less hydrophilic than the latter.

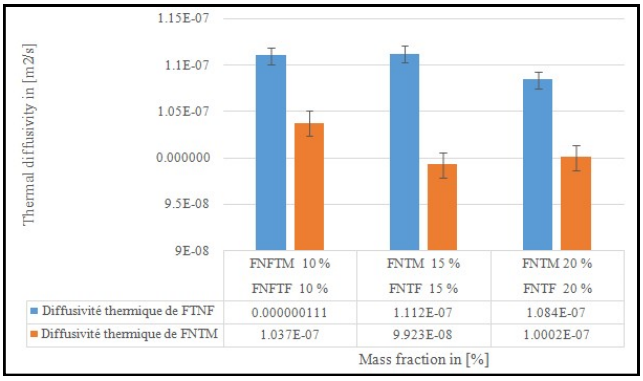

Figure 10. Evolution of thermal diffusivity as a function of the mass fraction of FNT (female and male)

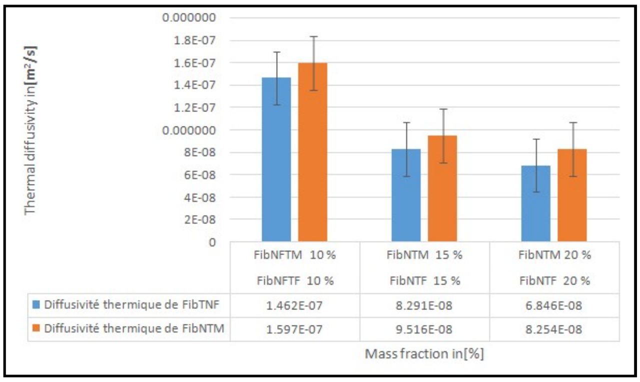

Figure 11. Thermal evolution as a function of the mass fraction of FibNT (female and male)

Thermal diffusivity: Figures 10 and 11 show the variation of the thermal diffusivity (D) of the specimens as a function of the mass fraction of Borassus. The diffusivity D is determined by the so-called hot wire method for different temperature values. The measurements are taken three times for each specimen, and the values are the average of the three measurements. We notice in Figures 10 and 11 that the thermal diffusivity decreases as we increase the mass fraction of Borassus powder or fibers. The compaction pressure may be the cause of this decrease in thermal diffusivity. Indeed, the increase in compaction pressure and mass fraction has the effect of reducing the number of pores and consequently decreasing the amount of air in the specimens.

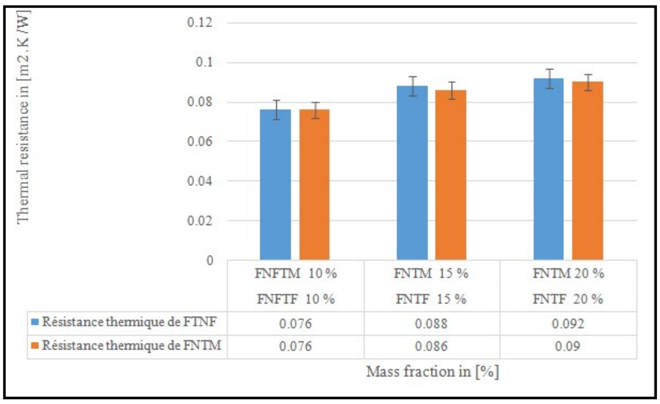

Figure 12. Evolution of the thermal resistance of FNT (female and male) as a function of the mass fraction

Variation of thermal resistance as a function of mass fraction: Figures 12 and 13 show the variation of thermal resistance as a function of the mass fraction in the production of thin plate specimens from Borassus residues and fibers from Chad.

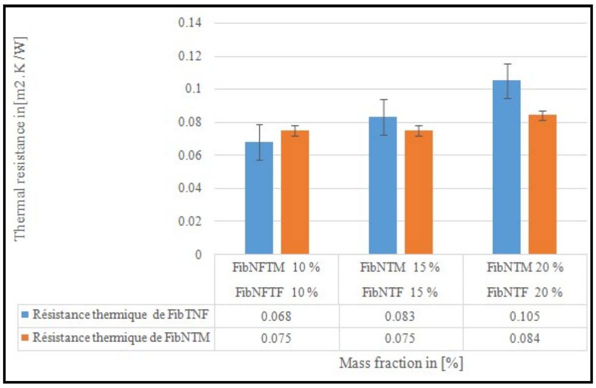

Figure 13. Evolution of the thermal resistance of FibNT (female and male) as a function of the mass fraction

According to figures 12 and 13, we can observe that: the thermal resistance automatically increases with the increase in the mass fraction of Borassus powder (male or female). In the same way, the increase in the mass fraction of Borassus fibers (male or female) increases the value of the thermal resistance of the specimens. The thermal resistance is the ratio between the thickness of the specimen and its thermal conductivity. If the value of thermal conductivity is high, then the resistance is low.We can say that the thermal resistance of the 15% FibNTF specimen is the highest, followed by that of the 10% FNTF specimen and the 15% FNTM specimen. Indeed, the more insulating a composite material is, the higher its thermal resistance, meaning its ability to resist heat exchange increases. It follows from this result that the higher the thermal conductivity of the materials, the lower their thermal resistance. These resultats are consistent with those of (Maarouf, 2023).

CONCLUSION

The objective of this work was to study the valorization of residues and fibers from Borassus in Chad and to evaluate the fiber and powder content on the properties of polypropylene-based composites. After the preparation and production of the specimens from different proportions of Borassus wood residues and fibers, we proceeded to determine the density, water absorption, diffusivity, and thermal resistance of our specimens. After the experimentation, we can draw the following conclusions: the variation of these parameters is due to the nature of the mass fractions of the residues and fibers in the composition of the specimens. Depending on the increase in the mass fraction of residues and fibers from Borassus wood from Chad, there was:

- An increase in density and a constant water absorption of the specimens based on male or female powders;
- A decrease in the thermal diffusivity of the specimens made from Borassus fibers or residues (male and female)
- A very slight variation and increase in thermal resistance.

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

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