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# Thermophysical and Mechanical Characterization of Composites from Wood Palmyra Residues

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**Abstract**

This work is a contribution to the promotion of local materials Chad construction, including wood Borassus aethiopum Mart or palmyra. Borassus is a palm tree whose wood is used in construction in Africa thanks to its mechanical resistance and weatherability, but the scientific characterization is still needed. The aim of this study is to evaluate the thermophysical and mechanical properties of the composites of the residue of this wood to begin to understand its outstanding performance in buildings. To this end, we have manufactured four composite materials from the residues of this wood and measured their thermophysical and mechanical properties. The results indicate that the Young's modulus, fracture resistance, conductivity and thermal diffusivity of the composites of Borassus wood residues depend on its structural composition and moisture content, behavior that can be exploited in construction works.

**Keywords:** Borassus aethiopum Mart, composite materials, wood palmyra residues, cast, Young's modulus, thermal conductivity, thermal diffusivity, palmyra composite.

## INTRODUCTION

Composite materials made from fibers (plant, glass, carbon, etc. ...) and different types of polymer matrixes are an important organic products class which is characterized by numerous application possibilities [1]. The wood-plastic composite or wood-resin are formed by polymerizing a monomer in the empty pores of the wood, fiber or solid flour. The polymer matrix has the function to distribute the load between the fibers and ensure the assembly and adhesion between them [2]. Wood is a heterogeneous and porous natural composite material that has several levels of well-organized cellular structure [3]. As part of this work, we are interested in wood Borassus aethiopum Mart or palmyra which is a spermaphyte angiosperm plant found in tropical regions of Sahelian Africa precisely in northern Cameroon and in the southern zone of Chad. This wood is the main material in traditional constructions and semi-traditional habitats, sheds and fence posts of residential areas and fields. Its operations in Chad, remaining archaic today lost more than 50% of the total volume of timber of a dejected tree (the sapwood, the heart and the upper snoring (Photo 1). It is that constitutes a shortfall economically when we know that this wood takes about thirty years to mature. The recovery of palmyra wood residues thus constitutes an environmental challenge and an economic stake in operating the Chadian palmyra.

This study aims to characterize thermophysically and mechanically composites from the residues of this wood for their use as thermal comfort material in housing, tiling and paving. To evaluate the mechanical and thermal characteristics, we have developed four types of composite materials consisting of polymer matrix (resin, polyethylene terephthalate and polyethylene) and reinforcements (flour and fibers of palmyra wood). Previous studies [4, 5] have determined the characteristics of this thermo mechanical and pure wood.

## EXPERIENCE

The composite materials used in our experiments as inclusions, the resin (Acrylic polyethylene methacrylate), polyethylene terephthalate and polyethylene, which are thermosetting and thermoplastic polymer matrices [1]. The reinforcements are made of palmyra wood residues from Chad as fibers of sapwood or flour heart of snoring crushed by hand. The raw material was provided by the Faculty of Exact and Applied Sciences of the University of N'Djamena as a trunk. The palmyra was cut in a village in the Department of Chari Chari-Baguirmi region at 11°51.33' north latitude and 11°04.45' east longitude. The residues are tacked in snoring and sapwood of palmyra in the Laboratory of Study and Research in Industrial Technologies (LERTI) of the Faculty of Exact and Applied Sciences. The palmyra is split and dried in the sun so that residues can not degrade in contact with moist air because of its high sugar levels [3]. The constitution of the palmyra, particularly rigid, makes the collection delicate and painstaking residues. We have successively used an ax, a chisel, a mass, a hoe (Photo 2) and a manual grinder. After milling, the flour is calibrated through a sieve to obtain a fine particle size (Photo 3).

In the manufacture of test specimens, palmyra residues are mixed with the resin in a container at a dose of 66% of resin powder and 34% of its liquid (by volume) with 62 g of wood flour for 2 minutes (Photo 4). The same process is repeated for Polyethylene (PE) and polyethylene terephthalate (PET), but the mixing time is very short. The fibers are oriented in the direction of polymer flow in order to obtain good mechanical properties and improved stiffness. Mixing fibers and resin was placed in the mold (Photo 5) and subjected to a compaction pressure of 7 bars using a manual hydraulic press type ENERPAC maximum pressure 700 bars with a pressure gauge capacity 70 bars for one hour before removal of the specimen. PE and PET polymer is melted in a container with a bottle of butane gas for a heating time 2h30. After melting, we poured the first layer of PE or PET in the mold. Then we spread the fibers of the sapwood woven (FAT) or none woven (FANT) on the batter into the mold before the pass under the compacting pressure for at least 5 minutes before removal from the mould [6].

The preparation of specimens diagram is given in Figure 1.

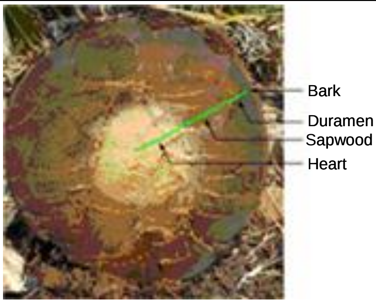


**Photo 1:** Morphology of the palmyra tree.

**Photo 2:** Splitting Technical and obtaining residues of palmyra.

**Photo 3:** Screening of residues of palmyra.

**Photo 4:** Kneading reinforcement resin mixture.

**Photo 5:** Implementation of the mixture into the mold.

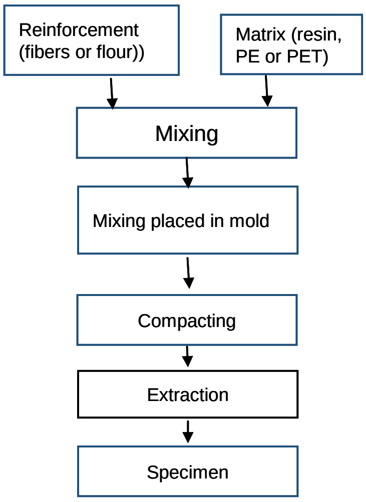


**Figure 1:** Flowchart specimens manufacturing.


**Photo 6:** Different types of test pieces produced and stored in Solid Mechanics Laboratory of LERTI at room temperature of 24 °C.

The four types of composite (resin + Flour, PE + Flour, PE + PET + FAT and PE + FANT) are dried in the open air for 15 to 30 days in the Solid Mechanics Laboratory of LERTI to stabilize their weight (Photo 6) as recommended in references [7, 8].

Test pieces from 55 mm in length, different widths (41, 42 and 43 mm) and different thicknesses (14, 15, 16, 17 and 18 mm) are subjected to compression tests using a universal testing machine, Type WP300 whose maximal capacity is 20 kN.

For the determination of thermophysical properties, we used a graduated digital thermometer from -50°C to 280°C with an accuracy of 0.1°C instead of the thermocouple, a calibrated electrical 0.1g precision balance, a stopwatch, the clay to isolate the edges of the sample and ensure the assumption unidirectional spread and a hot plate with a maximum power of 630W to a maximum temperature of 370°C (Image 7).

The specimen is placed by its uninsulated face $S_1$ on the plate heated to temperature $T_1$ = 150 °C constant for the resin and at the temperature $T_1$ = 100 °C for PET and PE. On the opposite side $S_2$, it falls every five minutes the change in $T_2$ temperature until stabilized with the digital thermometer.

For the measurement of the diffusivity, is sent on one of the faces of a test piece with parallel faces a luminous flux of high power at a temperature $T_1$ = 137 °C for a very short time. A digital thermometer with graduated numerical value from -50 to 280 °C, in contact with the rear face can raise the elevation of its temperature $T_2$ when the front panel receives the luminous flux (Photo 8) as recommended in references [9;10].

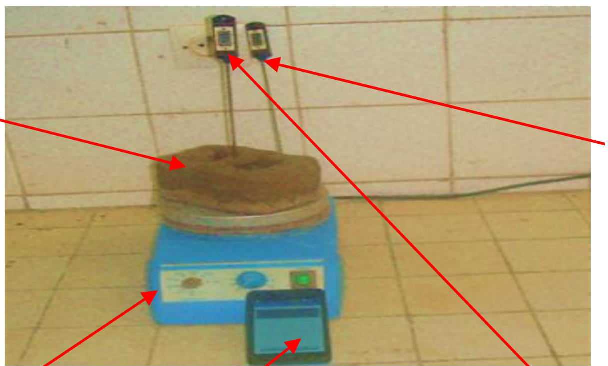


**Photo 7:** Method of guarded hot plate.

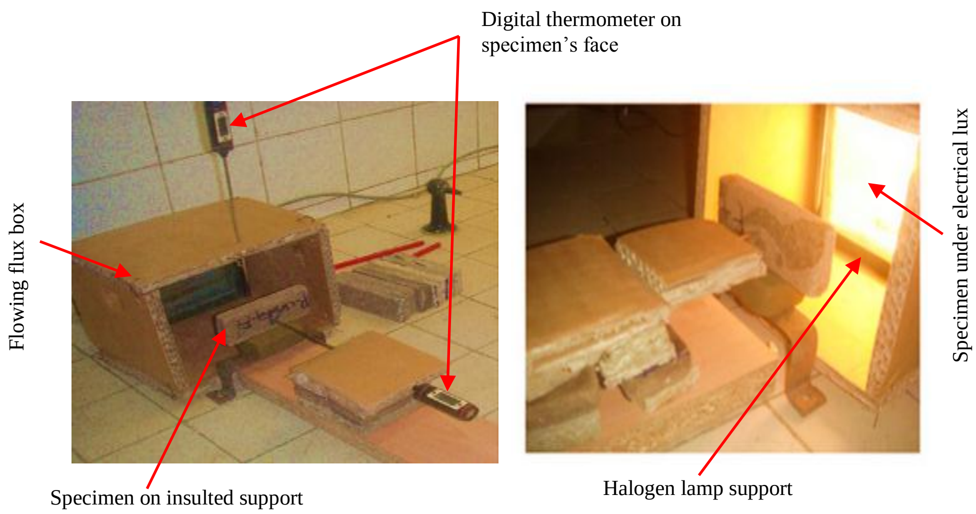


**Photo 8:** Flash Method measurement of thermal diffusivity.

## RESULTS AND DISCUSSIONS

In order to determine the mechanical behavior of composites of palmyra residue, we analyzed the stress-strain curves of different compression tests. For each trial, we considered the average results on the specimens to better understand the evolution of compression behavior.

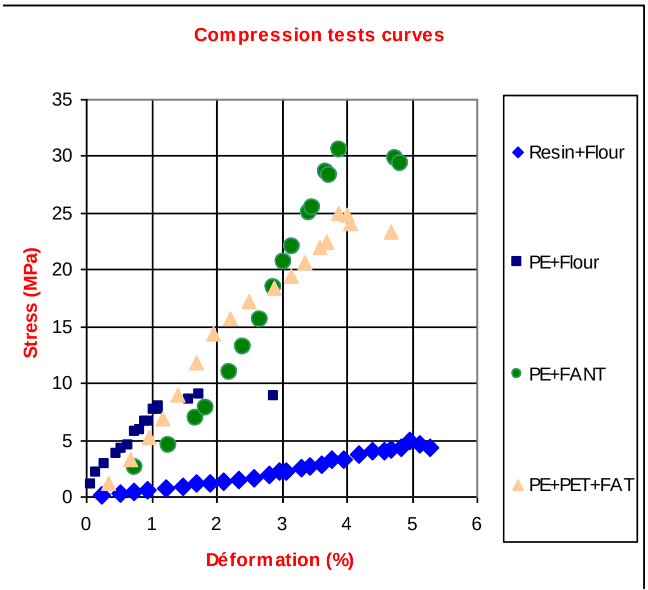


**Figure 2:** Curved compression tests of specimens.

Figure 2 shows the stress-strain curves of the samples (66% of palmyra residues with the resin or polyethylene) subjected to compressive generally have an elastic portion which indicates that the test pieces have a linear behavior in this area. Beyond the yield point, the test pieces behave according biasing the directions [11]. The value of the longitudinal elastic modulus (Young's modulus E) is calculated by measuring the tangent of the slope at the origin of deformation of the test pieces. The results are reported in Table 1.

**Table 1:** Mechanical properties of compression specimens.

| Specimen | Tensile strength $R_c$ (MPa) | Deformation ε **(%)** | Young's Modulus E (MPa) |
|---|---|---|---|
| Resin + Four | 4.947 | 4.974 | 98.03 |
| PE+ Flour | 9.034 | 1.750 | 626.27 |
| PE+PET+FAT | 24.952 | 3.871 | 635.44 |
| PE+FANT | 28.529 | 3.688 | 943.85 |

**Table 2:** Mechanical properties of pure sapwood specimen's in compression [5].

| Specimen | Tensile strength $R_c$ (MPa) | Young's Modulus E (MPa) |
|---|---|---|
| Sapwood radial direction of the fibers | 13.39 | 199.83 |
| Sapwood longitudinal direction of the fibers | 103 | 6400 |

Table 1 reveals that the maximal compressive strength of composite resin + flour is lower than that of PE + Flour. The PE + FANT specimen has a higher compressive strength than that of the PE + PET + FAT. As against the PE + FANT Young's modulus is higher than that of PE + PET + FAT and PE +Flour which in turn is higher than composite Resin + Flour.

From tables 1 and 2, it perceives that the transformation of palmyra residues improves the mechanical characteristics in compression with respect to the compression of sapwood in the radial direction of the fibers.

Many authors have shown that, at a very high level of fibers, the rigidity of the composite starts decreasing due to the wide variation of concentration, which results in a difference of stress distribution. The elongation properties and the tensile strength are decreased by increasing the amount of wood residues. In our study, we found that the polyethylene (PE) and Polyethylene *Terephthalate*, (PET) also play a role as well as the proportion of wood residues. Indeed, the matrix does not provide the same performance, whether the resin, PE and PET.

Comparisons are made of thermo-physical properties to see specimens that conduct heat poorly and the results presented are averages of tests on two specimens (Figure 3).

The curves in Figure 3 show the evolution of the temperature of test specimens as a function of time. For these curves, the transfer of heat evolves similarly in the 0 to 30 minute time interval corresponding to the temperatures ranging from 22.1 to 44.45°C, 22.1 to 45.4°C, 19.7 to 48.45°C and 21.4 to 46.5°C for Resin + Flour, PE + Flour, PE + FANT and PE + PET + FAT, respectively.

PE + Flour and PE + PET + FAT specimens conduct the heat in the same way up to the temperature of 42.8°C and 43.15; those of the resin + Flour and PE + FANT specimens deviate from 10 minutes to cross from 75 minutes with a temperature of 49.3°C to 49.8°C.

Between the time interval from 75 to 120 minutes, PE + Flour and PE + FANT specimens conduct the heat quickly compared to other specimens because of the PE effect on the reinforcements (fibers or flours). This leads us to conclude that the Resin + Flour and PE + PET + FAT specimens conduct less heat than PE + Flour and PE + FANT.

The main results of the thermal conductivity of the specimens are shown in Table 3.

**Table 3:** Values of the thermal conductivity of the test pieces to 17.36% moisture content.

| Specimen | Variation of temperature ΔT (K) | Conductivity λ $(Wm^{-1}K^{-1})$ |
|---|---|---|
| Resin + Flour | 100.4 | 0.046 |
| PE+PET+FAT | 51.6 | 0.049 |
| PE + FANT | 50.3 | 0.051 |
| PE+ Flour | 52.8 | 0.055 |

The values of thermal conductivity depend on the density of the test pieces, the moisture content, the compacting pressure and the position of collection of the temperature of the specimen. It appears in Table 3 that the thermal conductivities of the specimens in Resin + Flour and PE + PET + FAT remain below those of PE + Flour and PE + FANT. This shows that PE + Flour and PE + FANT are more conductive than the resin + Flour and PE + PET + FAT. That thermal behavior may be related to the effect of the porosity because the increasing of the compacting pressure reduced the space that air takes in the material and gives low thermal conductivity [12].

Table 4 shows that the developed composite are good insulators compared to sapwood and heart wood of the same palmyra of the study. This table confirms that the composites palmyra residues of our study are part of the class of good insulating materials.

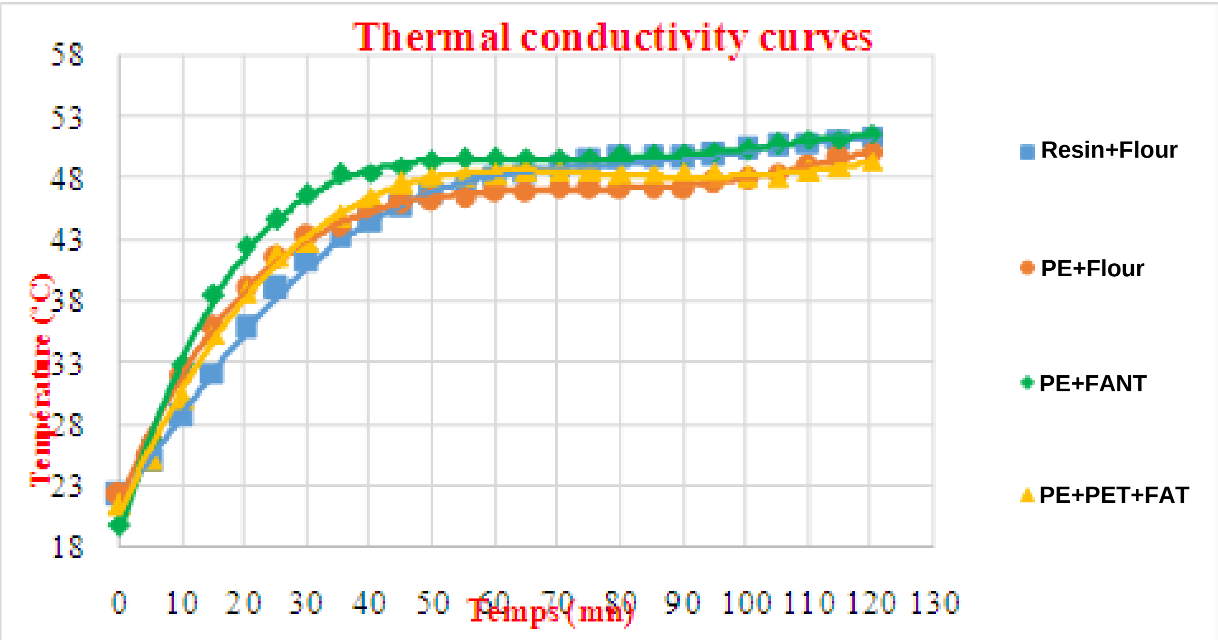


**Figure 3:** Thermal conductivity curves of specimens.

**Table 4:** Comparison of thermal conductivity values with others [4, 13].

| Our study materials | | | | | | | Insulation materials | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | Resin + Flour | PE+PET + FAT | PE+PET + FANT | PE + Flour | Sapwood's palmyra | Heart's palmyra | expensed Liege | Glass wool | Wool | Asbestos cement | Polyurethane | Polystyrene | Polychlorure of vinyl | Cotton |
| Conductivity $\lambda$ ($Wm^{-1}K^{-1}$) | 0.046 | 0.049 | 0.051 | 0.055 | 0.121 | 0.116 | 0.043 | 0.035 | 0.035 | 0.08 | 0.03 | 0.04 | 0.031 | 0.059 |

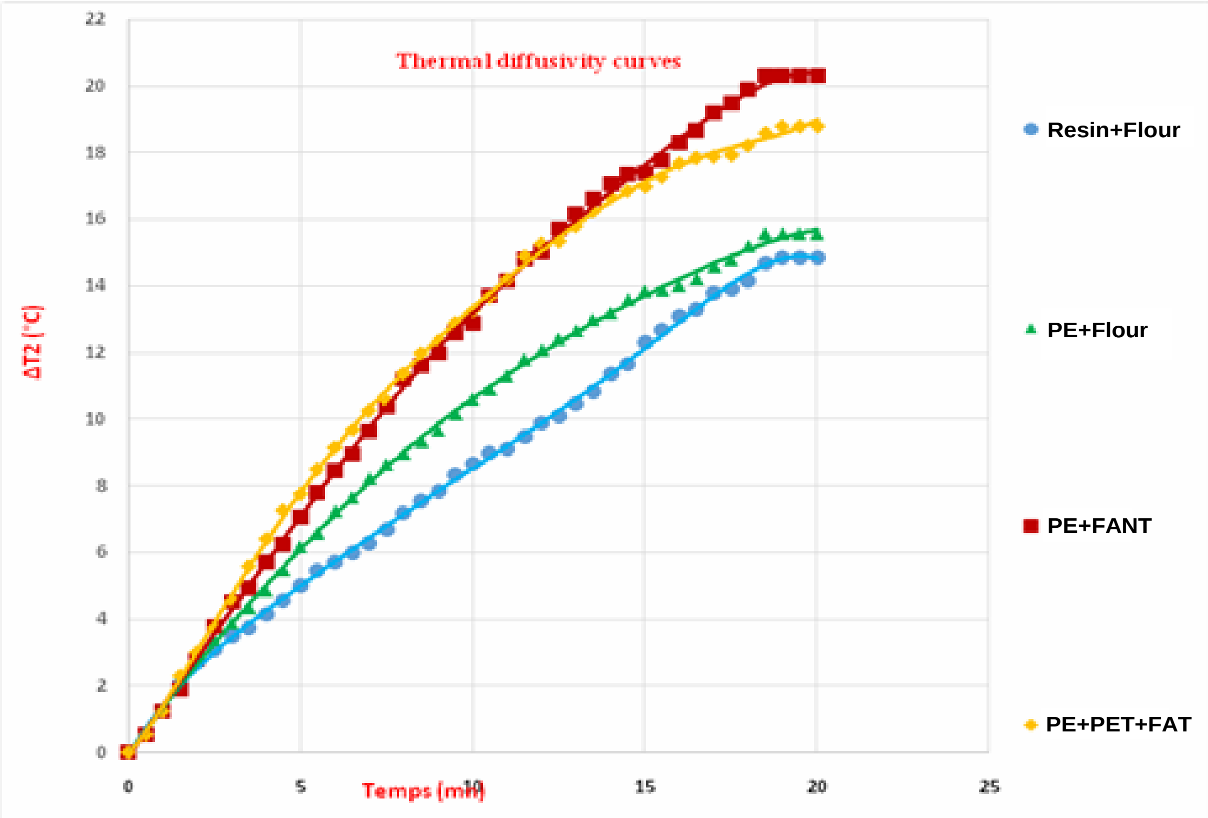


**Figure 4:** Thermal diffusivity curves of specimens.

**Table 5:** Values of the thermal diffusivity by the flash method.

| Our study materials | | | | | Other materials [14] | | | |
|---|---|---|---|---|---|---|---|---|
| Specimen | Resin+Flour | PE+FANT | PE+Flour | PE+PET+FAT | Panel of rigid fibers | PVC | panel of semi-rigid fibers | OSB |
| $\Delta T_2$ (°K) | 14,84 | 20,15 | 15,55 | 18,80 | | | | |
| Thermal diffusivity ($m^2/s$) | $8.91.10^{-8}$ | $7.26.\ 10^{-8}$ | $1.07.\ 10^{-7}$ | $1.02.\ 10^{-7}$ | $8.5.10^{-8}$ | $1.21.\ 10^{-7}$ | $1.2.10^{-7}$ | $1.10^{-7}$ |

According to Table 5, we realize that the Resin + flour and PE + FANT agglomerated residues of palmyra diffuse weakly heat than the PE +flour and PE + PET + FAT.

## CONCLUSION

The results of this work was to evaluate the mechanical and thermo-physical properties of four types of composite (Resin + Flour, PE + PET + FAT, PE + flour and PE + FANT) of Chadian palmyra, by experimental measurements have possible to infer that these composites are among the best known thermal insulators. Composite Resin + Flour and PE + PET + FAT are better insulators against PE+ Flour and PE + FANT. In addition, their thermal proprieties are influenced by the moisture and their geometrical defects [15]. The thermal insulating nature of these composites depends strongly on the proportion and nature of the reinforcements (powder or fiber of the palmyra). Yves JANNOT [16] concluded that these properties vary depending on the proportion and the nature of the fibers. We also observed that increasing the proportion of fibers or flour improves the density and the mechanical performance of the test pieces, in particular the Young's modulus and the compression breaking stress.

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