Evaluation of the physical and thermal properties of fibers extracted from the trunks of Urenalobata and SidaStipulata plants

Abstract

This scientific work was carried out to investigate the properties (hygroscopic, physical and thermal) of fibers extracted from the UrenaLobata and SidaStipulata plants, in order to compare them with other fibers already used in the manufacture of panels or biosourced concretes. The fibers are manually detached from the plant trunk, then dried and studied. The results of the study revealed that UrenaLobata fibers are more sensitive to water. The water absorption rate and water content were respectively evaluated at 228.58% and 10.5% for UrenaLobata fibers and 220.94% and 8.6% for SidaStipulata fibers. For densities ranging from 111 to 193.31 kg/m3, the measured thermal conductivities are between 0.046 - 0.075 W/ mK for UrenaLobatafibers and 0.043 - 0.064 W/mK for SidaStipulata fibers. These results show that both types of fiber can be used in the manufacture of thermal insulation materials.

Keywords: UrenaLobata fibers, SidaStipulata fibers, Density, Water absorption, thermal conductivity

1. Introduction

The global energy consumption and carbon dioxide emissions in the building sector are estimated at 34% and 37% in 2021 **[1].** This is due to the fact that the building envelope is essentially made of cement bricks, which are materials capable of storing large quantities of energy and releasing it in the form of heat. In order to ensure thermal comfort in these homes, building occupants use ventilation and air-conditioning systems that increase energy consumption. The manufacture of cement and the use of concrete in building construction therefore have a major impact on energy consumption and carbon dioxide emissions. According to **Marinković et al [2],** global concrete production is estimated at 6 billion tonnes per year. For this reason, the production of new types of concrete (bio-sourced concretes) with good thermal performance and low environmental impact would be a relevant solution for reducing energy consumption in the building sector. As a result, a considerable number of scientific studies have focused on the use of plant fibers as reinforcing materials in concrete.

The advantage of using plant fibers in concrete reinforcement is that they are locally available, lightweight, biodegradable and offer excellent thermal and acoustic insulation properties **[3].** Several characterization studies have been carried out in the literature to assess the chemical, hygroscopic, physical and thermal properties of plant fibers. Some researchers have focused on chemical composition, determining the organic constituents of fibers such as cellulose, hemicellulose and lignin **[4, 5]. Khiari et al. [6]** carried out a study on Posidonia-Oceanica fibers, showing that they contain 61.8% cellulose (cellulose and hemicellulose) and 29.8% lignin. The same work was carried out by **Mbouyap et al. [7]** on Banana fibers. Their results showed the presence of 58.3% cellulose, 12% hemicellulose, 10% lignin and 29.7% extractables. Other researchers have evaluated the hygroscopic and thermo-physical properties, such as water absorption, density and thermal conductivity, of certain plant fibers. **Libog et al. [8]** determined the properties of fibers extracted from banana trunks. Their study showed that it has a water absorption rate between (347.1- 517.4%) and a density of (0.9-1.45 g/cm^3). The study of typha fibers by **Diaw et al. [9]** reveals high water absorption and low density (56.44 kg/m^3). To assess the thermal insulation potential of date palm fibers, **Ali et al. [10]** measured thermal conductivity for different densities. The results revealed that for densities of (176 kg/m^3- 260 kg/m^3), the fibers exhibit low thermal conductivities (0.0475- 0.0697 W/mK). A similar study was carried out on Posidonia-Oceanica fibers by **Hamdaoui et al. [11].** The authors varied the density from 17 kg/m^3 to 155 kg/m^3 and found that the thermal conductivity values of the fibers ranged from 0.046 to 0.070 W/mK.**Wei et al. [12]** investigated a rice husk insulating material. For densities of 200 kg/m^3 to 350 kg/m^3, the corresponding thermal conductivities are 0.051 W/mK to 0.053 W/mK.Several other types of fiber have been studied, such as flax fibers **[13],** jute fibers **[14],** flax fibers **[15],** pineapple leaf fibers **[16],** baobab trunk fibers **[17**], Diss and Doum fibers **[18].**From the results of these different studies, we can see that these plant fibers have variable hygroscopic and thermo-physical properties. This dispersion of fibers properties can be linked to development zones and conditions, structure (porosity) and chemical composition (lignin, cellulose, hemicellulose etc.), extraction zone (stem, trunk, leaves, nuts etc.) **[19, 20].**

However, no studies on the physical and thermal characterization of **UrenaLobata and SidaStipulata**plant fibers have been found in the literature. This article proposes the characterization of these two types of fibers in order to use them as reinforcement material in concrete or to produce thermal insulation boards.**UrenaLobata L. and SidaStipulata L**. are both wild plants in the Malvaceae family. With cylindrical trunks and essentially fibrous bark, these plants can reach heights of 1.5 m to 2 m. They grow during the rainy season in the south and southeast of Senegal. The long fibers extracted from the trunk of the UrenaLobata plant have been used for a long time by our ancestors to make ropes and weave mats. In this article, we focus on evaluating the physical properties (water absorption, density) and thermal conductivity of the fibers.

2- Materials and experimental methods

2.1 - Plant fibers

The studied fibers were extracted from UrenaLobata L. and SidaStipulata L. plants collected in the village of Koling / Sédhiou region / Senegal (Fig.1). The fibers were extracted manually, as the bark detaches easily from the stem. After extraction, the fibers were air-dried for 2 weeks.

Fig 1 **: a-** Urenalobata plant**, b-** Urenalobatafibers, **c-** Sida Stipulata plant, **d-** Sida Stipulatafibers

2.2- Water absorption rate

The water absorption rate of the fibers was determined by the distilled water immersion method. The fibers were first dried in an oven at 105°C for 24 h, then weighed. Placed in a tube pierced with small holes, the fiber-tube assembly was introduced into water at an average temperature of 27°C. Every 30 min, the fibers were removed from the water and lightly shaken to remove water from the surfaces, then weighed using a 0.01g precision balance. Weighing operations are repeated until the fiber mass has become constant. The water absorption rate is calculated by Eq. 1**[7, 8, 21].**

$$W_{abs} = \frac{m_h - m_i}{m_i} x\ 100(1)$$

$\boldsymbol{m_h}$: mass of humid fibers, $\boldsymbol{m_i}$: initial fibers mass

2.3- Water content

The moisture content of the fibers is determined by the oven-drying method. A sample of each type of fiber is weighed with a 0.01 g precision balance, then dried in an oven at 105°C for 48 hours. Fiber water content is calculated using Eq. 2:

$$M_c = \frac{m_s - m_i}{m_i} x\ 100 \qquad (2)$$

$\boldsymbol{m_s}$: Dry fiber mass

2.4- The bulk density

The density of a material is the ratio of its mass to its apparent volume. To evaluate density, the apparent volume (V) of the fibers is determined using a cylindrical mold, then their corresponding mass (m) is measured using a 0.01 g precision balance. The mass is calculated by the Eq 3:

$$\rho = \frac{m}{V} \qquad (3)$$

2.5- Thermal conductivity

Thermal conductivity was assessed using the thermal box method. A Plexiglas dial with dimensions of 27cm x 27cm x 5 cm was used to contain the raw fibers (fig.2). By increasing the compaction pressure of the fibers in the same dial, three densities were used to measure the thermal conductivities of the fibers

Fig. 2: Fibers sample

The principle of this method is to send a constant flow of heat (Φ) to one side of the sample using a heating resistance (Fig.3). With thermocouples attached to both sides of the sample, temperatures are measured when steady state is established. To minimize heat loss (C) through the box faces, the voltage is set so that the temperature in the box is slightly higher than the ambient temperature ($(T_b - T_a) < 1\,°C$). The heat transfer in the box is given by Eq. 4:

$$\varphi = \varphi_u + \varphi_p \qquad (4)$$

With: $\varphi = \frac{U^2}{R}$, the heat flux from the heating element

$\varphi_u = \frac{\lambda\, S}{e}(T_c - T_f)$: the heat flux that passes through the sample

$\varphi_p = C(T_B - T_a)$: the lost heat flux

Replacing these expressions in Eq. 4, we derive the expression for the thermal conductivity of the sample by Eq. 4:

$$\lambda = \frac{e}{S(T_c - T_f)}\left[\frac{U^2}{R} - C(T_B - T_a)\right] \qquad (5)$$

U: The voltage

R: Heating element thermal resistance

T_c: Heating face temperature

T_B: Box temperature

T_f: Cooling face temperature

T_a: Ambient temperature

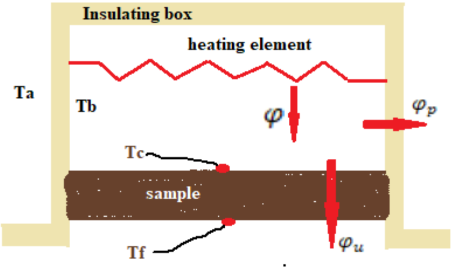

Fig. 3: Sample in thermal box

3-Results and discussion

3.1- Water absorption

The water absorption rate of fibers is an important parameter in determining the maximum amount of water that can be absorbed, and the maximum immersion time to reach water saturation. During the manufacture of bio-composite concrete, this quantity of water must be taken into account when assessing the optimum mixing ratio (water/binder) to ensure proper binder adhesion. Fig. 4 shows the evolution of water absorption rate as a function of fiber immersion time. It can be seen from Fig. 4 that during the first four hours of immersion, the fibers absorb water more rapidly. After four hours, their capacity to absorb water begins to diminish, reaching saturation after 14 hours of immersion. This is because plant fibers are cellulosic materials whose hydrophilic character is due to the fact that their structure is made up of many capillary pores. In addition, their structure contains a large number of hydroxyl groups linked to the presence of lignin and hemicelluloses, which are capable of binding large quantities of water molecules**[16, 21, 22].** In this study, maximum water absorption rates were 228.58% for UrenaLobata L. fibers and 220.94% for SidaStipulata L. fibers. Similar studies on plant fibers (Table 1), investigating the water absorption of different fibers, show that the water absorption values of UrenaLobata and SidaStipulata fibers are within the range of those of plant fibers found in the literature.

Table 1: water absorption rates of some fibres

Types of fibers	Water absorption (%)	Immersion times	Autors
Ananas Comosusfibers	268	24 h	**[16]**
Banana Fibers	347.1- 517.4	48 h	**[8]**
Raffiaviniferafibers	303-662	24 days	**[23]**
Hempfibers	62	13 h	**24]**
UrenaLobatafibers	228.58	14 h	**PW**
Sida Stipulatafibers	220.94	14 h	**PW**

PW: Present Work

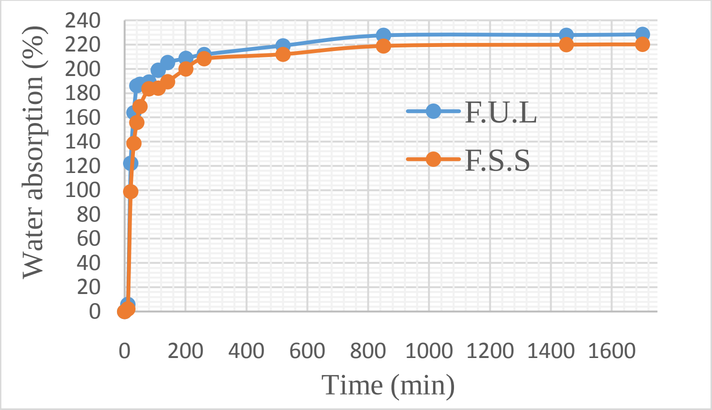

Fig. 4:Water absorption of fibers

3.2. Water content

Determining the water content provides information on the hygroscopic state of the fibers under ambient conditions. The water contents of the two types of fiber are shown in Table 2. The traces of water in the internal structure of fibers can be explained by the presence of hydroxyl groups in lignin and hemicellulose, the non-cellulose components of fibers. Through Van Der Wall-type hydrogen bonds, these components are able to bind water molecules in vapour form and, through the process of vapour diffusion and capillary condensation, water is formed in the fibers pores **[25].** Table 2 shows that the water content of UrenaLobata fibers (10.5%) is higher than that of SidaStipulata fibers (8.6%) under ambient conditions. This may be due to the fact that there are more hydroxide groups in UrenaLobata fibers. Table 2 shows the water content values of various plant fibers. It can be seen that the water contents of the fibers studied are in the same range as those of many fibers found in the literature.

Table 2: Water content of various fibers

Type of fibers	UrenaLobata	Sida Stipulata	Banana	Typha plant	Carnauba	Ficus Carica	Hibuscus Vitifolius	Bambou
Water Content	10.5	8.6	10.6-12.4	1.4	7.2	9.07	11.31	9.16
Autors	PW	PW	**[7]**	**[9]**	**[5]**	**[4]**	**[26]**	**[27]**

3.3-The bulk density

The bulk densities of both types of fibers were measured and their values are shown in Table 2. In general, plant fibers have lower bulk densities than conventional fibers. The low density of plant fibers can be attributed to the high internal porosity of their structures, which results in the high water absorption of plant fibers **[9].** This is due to the presence of amorphous components such as lignin and hemicelluloses, whose structure contains large quantities of voids. Table 2 shows that UrenaLobata fibers have a higher density than SidaStipulata fibers. This result can be justified by the fact that UrenaLobata fibers have less pores. In addition, the fibers studied have lower densities than date palm **[10]** and Diss or Doum**[18]** fibers. However, typha plant fibers are much lighter than the fibers studied. This dispersion of plant fiber density values is linked to several parameters: extraction position on the plant, development zone, chemical composition, etc.

Type of fibers	UrenaLobata	Sida Stipulata	Palmier dattier	Diss and Doum	Typha plant
Density (kg/m^3)	239.63	201.14	176-210	850 and 447	56.44
Autors	PW	PW	**[10]**	**[18]**	**[9]**

Table 3: Densities of different fibers

3.4-Thermal conductivity

In order to assess the thermal insulation potential of the fibers, their thermal conductivities were measured using the thermal box method. The conductivity values measured for both types of fiber are shown in Table 5. The evolution of thermal conductivity as a function of density for each fiber type is shown in Fig. 5.

Initially, Fig. 5 shows that the thermal conductivity of the fibers increases as the density of the fibers increases; this is observed for both types of fiber. Indeed, an increase in density leads to a decrease in the porosity of a sample. However, in order to increase the density, it was necessary to increase the quantity of fibers in the same dial, which also means increasing the compaction pressure to fill the dial. The porosity of the sample decreases with increasing fiber quantity in the same dial. This justifies the fact that thermal conductivity increases as density increases. Similar studies on rice husk and Posidonia-Oceanica fibers, by Wei et al. **[12]** and Hamdaoui et al. **[11]** respectively, have also shown that the thermal conductivity of fibers varies in the same direction as density.

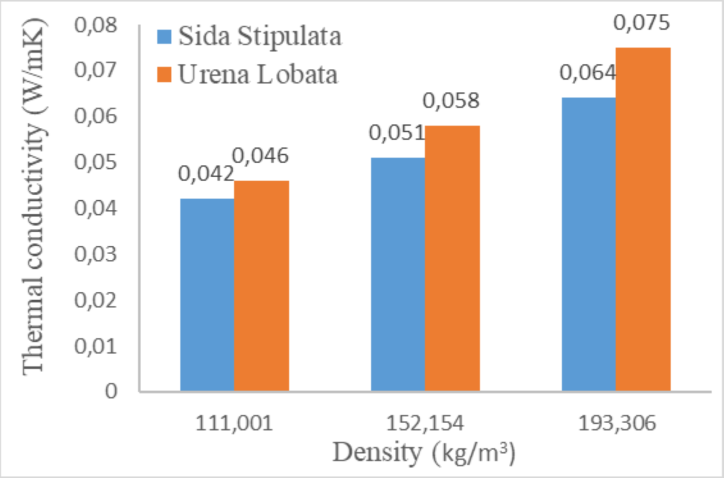

Fig. 5: Thermal conductivity as a function of density

Secondly, it can be seen from Fig. 5 that Stipulatasida fibers showed better thermal conductivity values than UrenaLobata fibers. In fact, even though they are both of plant origin, these fibers do not have the same internal structure, which is an important parameter in terms of a fiber's properties. As shown in Table 3, the density of UrenaLobata fibers is higher than that of SidaStipulata fibers. For this reason, UrenaLobata fibers are less porous and therefore more heat-conductive. This is why the superior thermal conductivity of UrenaLobata fibers was observed.

Table 4 illustrates the thermal conductivity values of the fibers studied and those of some fibers found in the literature. As can be seen, the fibers studied (Urena and sida) presented low thermal conductivities that are very close to those of other fiber types already studied for use as thermal insulation materials.

Table 4: Thermal conductivity of different types of fibers.

Type of fibers	UrenaLobata	Sida Stipulata	Race Straw	PosidoniaOceanica	Date palm surface fibers
Thermal conductivity (W/mK)	0.046-0.075	0.043-0.064	0.051-0.053	0.043-0.070	0.0475-0.0697
Autors	**PW**	**PW**	**[12]**	**[11]**	**[10]**

4. Conclusion

The development of composite materials using plant fibers requires a thorough understanding of their properties. For this reason, UrenaLobata and sidaStipulata fibers have been characterized. The study consisted in determining the water absorption, density and thermal conductivity of the fibers. The results showed that both types of fiber have a higher water absorption capacity than conventional fibers.However, both types of fiber are lightweight and have low thermal conductivities. A simple comparison shows that these fibers have properties similar to those found in the literature. They can therefore be used in the manufacture of biosourced panels and concretes.

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