Sigma J Eng & Nat Sci 38 (4), 2020, 2069-2081

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Review Article

COMPARISON OF TWO TYPES OF BINDERS NATURALS ON THE MECHANICAL AND THERMAL PROPERTIES OF TYPHA LEAF POWDER PANELS

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Received: 11.11.2019 Revised: 28.12.2019 Accepted: 16.09.2020

ABSTRACT

This paper is a contribution to the valorization of Typha Australis as building material. The aim of this article is to develop 100% vegetal insulation boards based on powder of typha leaves and gum arabic and starch binders. The comparison of the nature of the binder on the mechanical and thermal properties was carried out. The influence of binder content on the mechanical and thermal insulation properties of panels of typha-gum Arabic and typha-starch was examined too. The density is very small in the case of starch than in the case of gum arabic. The typha-gum arabic panel is 1.17 times more dense than that of typha-starch, for 33.33 % binder. The typha-starch board, for 50 % binder, showed a good compressive strength (1.05 MPa) and is 1.36 times stronger than the typha-gum arabic board. The best thermal conductivity is obtained with the typha-starch board (0.051 $W.m^{-1}.K^{-1}$) for 33.33 % binder. The thermal conductivity values are close to or lower than many of natural insulating materials. It was also concluded that the typha - gum arabic panels are more effusive.

Keywords: Typha, gum arabic, starch, mechanical strength, thermal conductivity, thermal effusivity.

1. INTRODUCTION

In order to reduce the effects of global warming, we must necessarily reduce the greenhouse gas emissions, especially CO_2. Global emissions of greenhouse gases (GHGs) covered by the

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Kyoto Protocol are increased by 80 % between 1970 and 2010 according to the IPCC (Intergovernmental Panel on Climate Change). The building sector, in particular the construction sector, contributes indirectly and directly to CO2 emissions and energy consumption. Heating and cooling in buildings and industry account for about 40 % of global energy consumption according to the International Energy Agency (IEA), 70 % of which comes from fossil fuels. These end-uses accounted for 30 % of global carbon dioxide (CO_2) emissions in 2012. At the national level, the household sector accounts for more than 58.7 % of energy consumption (according to Senegal's Energy Information System) [1] and 59 % of CO_2 emissions (according to the second national communication to the United Nations Framework Convention on Climate Change) [2]. During all the phases of its life a building strongly affects the environment through the use of natural resources and energy. In view of these figures, and the context in which the building sector faced with new agro-resources materials, is a realistic alternative. Their potential for the improvement in terms of thermal performance seems important. Indeed, studies have shown that the use of insulating materials in the building significantly reduces the energy consumption [3 - 7]. Cerezo [8] evaluated the evolution of the mechanical and thermal characteristics of hemp concrete according to the binder dosage. It has achieved excellent performance of hemp concrete as a thermal insulation with conductivities ranging between 0.06 and 0.19 $Wm^{-1}.K^{-1}$ for densities ranging from 200 to 840 kg/m^3. The compressive strength is at the order of 0.25 MPa to 1.15 MPa. Umurigirwa [9] in his works, studied the mechanical and thermal performance of a new 100 % natural material made from hemp and a starch binder. He noted that the compressive strength is higher than that of hemp-lime concrete of low density (about 250 kg/m^3) with a resistance of 0.8 MPa compared to 0.25 MPa. The values of the thermal conductivity of the hemp-starch concrete obtained are respectively 0.04905 to 0.0506 $W.m^{-1}.K^{-1}$. It deduces that the use of starch binder and of hemp hurds can reduce energy consumption compared to lime hemp concrete. N. Cuk et al. [10] studied the influence of two types of binder on the properties of a wood particle board. They showed that the mechanical properties of particle boards produced were better with the melamine-formaldehyde resin (flexural strength of 13.42 MPa) than with the melamine-urea-formaldehyde resin (11.06 MPa). Zach et al. [11] studied the thermal performance of different types of fibers (hemp, jute and linen). They concluded that the best thermal insulation properties were obtained with hemp and with a thermal conductivity coefficient of 0.0405 $W.m^{-1}.K^{-1}$. Flax and jute gave values of 0.0442 $W.m^{-1}.K^{-1}$ and 0.0482 $W.m^{-1}.K^{-1}$, respectively. Contrary to these works, our study focuses on the construction material combining a vegetable fiber of the typha plant and a matrix of natural origin. Typha is a very common plant in Senegal's wetlands. Typha australis is found on the banks of the Senegal River and its annexes, in the marigots, channels, cultivated plots (rice paddies in particular) and irrigation canals. The Mauritanian and Senegalese populations who share the river valley are worried by the invasion of the plant and its consequences. The leaves represent about 80 % by weight of the entire biological mass and thus constitute the largest part of the plant. Most of the volume of the leaf consists of a very spongy, porous surface tissue that serves to stiffen and aerate the leaf. This spongy tissue enhances the insulating capacity of this plant [12]. Applied to the field of construction, there is some rare research on the use of typha as a material ([13 – 15]). Diatta et al. [13] also determined the thermal conductivity of typha concrete as well as the mechanical strength corresponding to each sample. The best thermal conductivity obtained is 0.126 $W.m^{-1}.K^{-1}$ for a percentage of 3 % of typha. The corresponding mechanical resistance at the 28th day is 0.89 MPa. The insulating character of Typha has also been proved by the study of Abdelhakh et al. [14]. They made reinforcements of pieces of typha leaves gradually in a cement mortar. They showed for a mass fraction of typha varying from 0 % to 3.5 %, the value of the conductivity decreases from $1W.m^{-1}.K^{-1}$ and up to 0.4 $W.m^{-1}.K^{-1}$. The mechanical results showed a strong decrease in compressive strength especially from 2.5 % of typha. Results showed that the thermal behavior of composite materials vary from 0.065 to 0.112 $W.m^{-1}.K^{-1}$ [15]. However, the use of a binder of vegetable origin and the influence of the nature of the binder are not exploited.

The peculiarity of this study is to develop panels of 100 % vegetable typha and to determine the properties (density, com pressive strength, thermal conductivity and thermal effusivity) of panels according to the nature of the binder.

2. EXPERIMENT

The typha panels tested are made from typha leaf powder and binders of vegetable origin (gum arabic and starch of corn).

2.1. Marerials

The binders used here is gum arabic Fig. 1 and starch Fig. 2. Gum arabic comes from a tree called acacia and is available in the market as crystals or powders. The density of gum arabic was 515 kg/m^3. The moisture content of gum arabic was 16.5 %. The water content is obtained using an oven at a temperature of 105 ° C. Crystals of gum arabic were immersed for a few days in water before being mixed to obtain a viscous liquid that sticks. The mass ratio between the gum arabic and water (G / E) was taken to be 1:2. The water content is defined by the following relation: $\% = \frac{m-m_0}{m_0}100$ (1)

With m_0 the mass of the sample in the dry state, m (kg) the mass of the sample in a given wet state.

The starch of corn used was obtained on the market and has a density of 466.48 kg/m^3 and a water content of 18.69 %. The water content is determined in the same way as for starch.The density was measured according to French standards NF ISO 11272. First we determined the bulk density by weighing a mass of samples in 500 mL test pieces. The experiment was repeated 3 times. Regarding starch, it is not a natural thermoplastic material and must be plasticized. The process of transforming the starch into thermoplastic consists in mixing the starch powder with water heated to 70 ° C. and kneading it finally to obtain a sticky liquid. The mass ratio between the starch and water (S / E) was taken to be 1:3.

Figure 1. Gum arabic crystals

Figure 2. Starch

The leaves of typha australis used were extracted in the zone of Niayes in Dakar. The chemical composition of typha australis [16] is shown in the table 1.They were dried under the sun for three weeks before being cut into small pieces. After cutting, the sheets were thus transformed into powder by a disk mill (Fig. 3). The results of the granulometric analysis of the Typha used are illustrated in Fig. 4. The density of typha material was 128.4 kg/m^3. The average moisture content of typha material determined by weighing of typha sample before and after drying for 24 h at 105 °C was found 12.24 %.

Table 1. Chimical characterization of typha fibres [16]

	Lignin (%)	**Cellulose (%)**	**Hemicellulose (%)**	**Holocellulose(%)**
Typha australis	26	69	10	79

Figure 3. Typha leaves powder

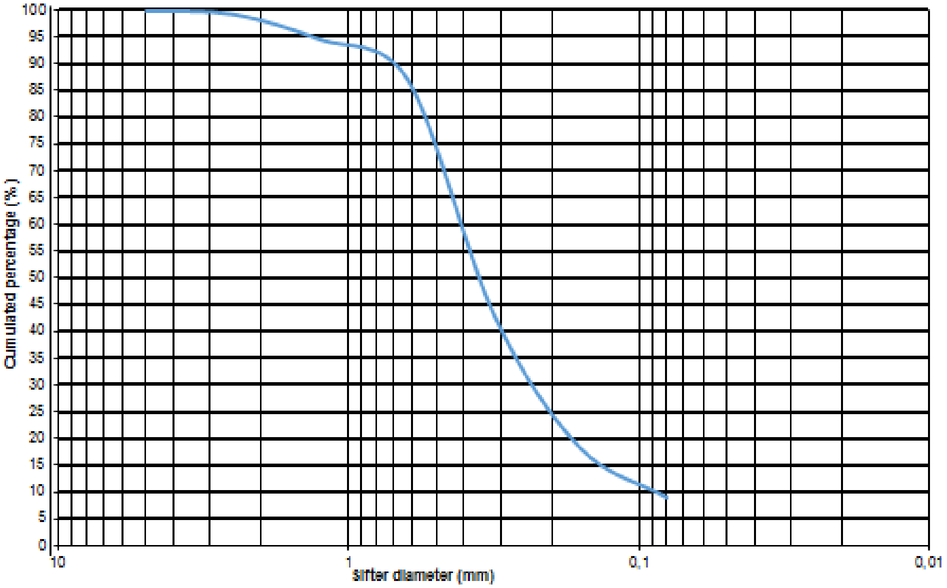

Figure 4. Granulometric graph of typha used

2.2. Preparation of samples

Experimental mixture consisted of powder of typha leaf, of binder (gum arabic or starch) and water. Samples were made by mixing typha material with the binder material in the beater during 5 min. The mixture was malaxated using a mixer type E095. The mixer had a specific speed of 62 and a capacity of 5 L. The mass composition of the different samples is given in Table 2. For the mechanical tests, a mould of dimensions 4 cm × 4 cm × 16 cm was used to prepare samples and the thermal test samples were also prepared in a mould of dimensions 100 mm × 100 mm × 10 mm. The material obtained was poured in the moulds and tamped. The specimens were cured for one day in an indoor climate and then removed from the forms. Curing was continued under the air during 15 days. The panels based on typha-gum arabic and typha-starch type powders have different binding / water mass ratios but have the same mass proportions of typha and binder. The masses of the various constituents of the typha panels are shown in the tables. 2 and 3.

Table. 2. Mass Composition of Typha - Gum Arabic Panels

Samples	Binder percentage (%)	Binder mass(g)	typha leaves powder mass (g)	Water mass (g)
$\boldsymbol{E_1}$	33.33	48	96	96
$\boldsymbol{E_2}$	38.23	52	84	104
$\boldsymbol{E_3}$	47.46	56	72	112
$\boldsymbol{E_4}$	50	60	60	120

Table. 3. Mass Composition of Typha - starch Panels

Samples	Binder percentage (%)	Binder mass(g)	typha leaves powder mass (g)	Water mass (g)
$\boldsymbol{E_1}$	33.33	48	96	144
$\boldsymbol{E_2}$	38.23	52	84	156
$\boldsymbol{E_3}$	47.46	56	72	168
$\boldsymbol{E_4}$	50	60	60	180

2.3. Testing methods

Density, compressive strength, thermal conductivity and thermal effusivity were measured on dried specimens in the air.

2.3.1. Physical test

We determined the density of the materials. Bulk density was determined using a 0.01 g precision scale for weighing and 0.01 mm precision callipers to measure sample sizes. For each composition, 5 measurements were made, in order to obtain an average.

2.3.2. Mechanical tests

The mechanical tests were performed on the specimens. The compression tests were performed using the universal testing machine, in accordance with the standard NF EN 196-1. This characterization was done by using an E0160 type mechanical press with a maximum force of 250 kN. The specific speed of the force application was 2 kN/sec. For compression tests, the specimens were placed as described in Fig. 5.

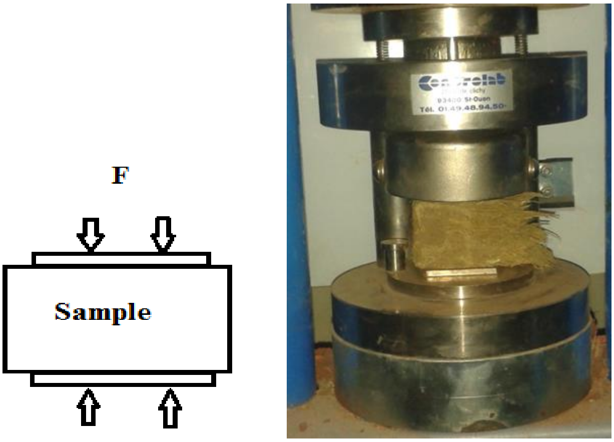

Figure 5. Compression test

A compressive strength test has been performed on four specimens per mix. The specimens are compressed with a force to measure the constraint. Stress, σ in MPa, was calculated using Eq. (1)

$$\sigma = \frac{F}{S} \tag{1}$$

S is the sample section in mm^2, F is the force applied (N)

2.3.3. Thermal test

All thermophysical experiments were performed using samples of dimensions 100 mm × 100 mm × 10 mm [17]. The thermal conductivity and effusivity of samples were determined simultaneously using a transient method [17], [18]. The method used is the hot plate transient method. The different elements that make up the experimental device represented in Fig. 6 are as follows. The hot plate method was then used in an asymmetrical configuration. It consists in embedding a heating element on which a thermocouple was fixed, between the material to be characterized and a 5 cm thick polystyrene plate. The whole set was put between two aluminium blocks with a thickness 4 cm. A flux step is sent in the heating element and the temperatures Ts (t) at the center of the heating element is recorded. The processing of the recording of Ts (t) is realized by supposing that the heat transfer at the center of the heating element is 1D. The temperature at the level of the aluminium block is constant.

In this case, the thermal quadrupole method [19] can be used to solve the thermal transfer problem. Indeed, in Laplace's space, the heat equation no longer depends on the space variable. This method makes it possible then to relate the input and output flows and temperatures using a passing matrix.

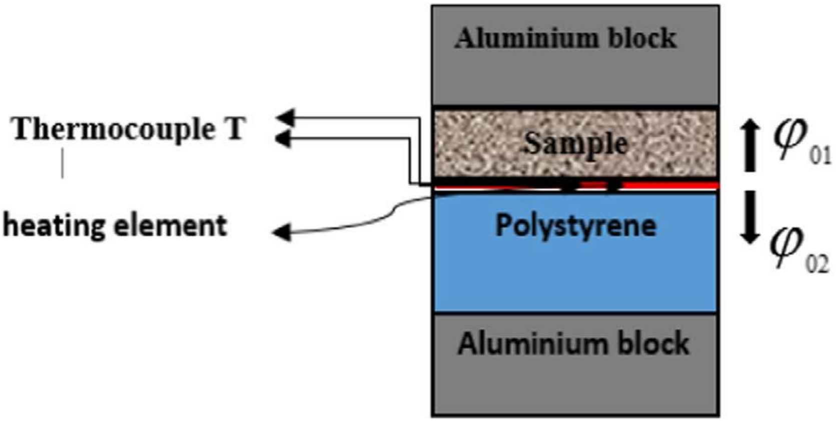

Figure 6. Schema of the experimental asymmetrical hot plate device

$$\begin{bmatrix}\theta_s\\ \phi_{01}\end{bmatrix}=\begin{bmatrix}1 & 0\\ CsSp & 1\end{bmatrix}\begin{bmatrix}1 & R_C\\ 0 & 1\end{bmatrix}\begin{bmatrix}A & B\\ C & D\end{bmatrix}\begin{bmatrix}0\\ \phi_1\end{bmatrix}\begin{bmatrix}A_1 & B_1\\ C_1 & D_1\end{bmatrix}=\begin{bmatrix}0\\ \phi_1\end{bmatrix} \tag{2}$$

$$\begin{bmatrix}\theta_s\\ \phi_{02}\end{bmatrix}=\begin{bmatrix}A_i & B_i\\ C_i & D_i\end{bmatrix}\begin{bmatrix}0\\ \phi_2\end{bmatrix} \tag{3}$$

With:

$$A=D=\cosh\left(\frac{E}{\lambda}\sqrt{p}\,e\right)\ ;B=\frac{\sinh\left(\frac{E}{\lambda}\sqrt{p}\,e\right)}{ES\sqrt{p}}\ ;\ C=ES\sqrt{p}\sinh\left(\frac{E}{\lambda}\sqrt{p}\,e\right)$$

$$A_i=D_i=\cosh\left(\frac{Ei}{\lambda i}\sqrt{p}ei\right)\ ;\ B_i=\frac{\sinh\left(\frac{E_i}{\lambda_i}\sqrt{p}\,e_i\right)}{E_iS\sqrt{p}}\ ;\ Ci=E_iS\sqrt{p}\sinh\left(\frac{E_i}{\lambda_i}\sqrt{p}\,e_i\right)$$

λ is the sample thermal conductivity; E the sample thermal effusivity; e the sample thickness; λ_i the polystyrene thermal conductivity; E_i the polystyrene thermal effusivity; e_i the polystyrene thickness; θ_s the Laplace transform of the temperature $Ts(t)$; Cs the thermal capacity of the heating element per area unit: $Cs = \rho_s c_s e_s$; R_C the thermal contact resistance between the heating element and the sample; ϕ_1 the Laplace transform of heat flux input on the upper aluminium block; ϕ_2 the Laplace transform of heat flux input on the lower aluminium block; ϕ_{01} the Laplace transform of the heat flux density living the heating element (upstream); ϕ_{02} the Laplace transform of the heat flux density living the heating element (downstream)

After developing the matrix products (2) and (3), the following relations were obtained:

$$\phi_{01}=\theta_S\frac{D1}{B1} \tag{4}$$

$$\phi_{02} = \theta_S \frac{D_i}{B_i} \tag{5}$$

The total flow was: $\phi_0 = \phi_{01} + \phi_{02}$ (6)

$$\phi_0 = \theta_S \left(\frac{D_1}{B_1} + \frac{D_i}{B_i} \right) \tag{7}$$

Inferring θ_s from expression (7),

$$\theta_s = \phi_0 \frac{1}{(\frac{D_1}{B_1} + \frac{D_i}{B_i})} \tag{8}$$

Was finally obtained.

The principle of the method is thus to estimate the values of the parameters λ and eventually E which minimize the sum of the quadratic errors $\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}}[\boldsymbol{Ts}(\boldsymbol{t_i}) - \boldsymbol{Ts_{mod}}(\boldsymbol{t_i})]$ between the experimental curve $\boldsymbol{Ts}(\boldsymbol{t}) = \boldsymbol{Ts}(\boldsymbol{0}, \boldsymbol{t})$ and the theoretical curve $\boldsymbol{Ts_{mod}}(\boldsymbol{t}) = \boldsymbol{Ts_{mod}}(\boldsymbol{0}, \boldsymbol{t})$ calculated with relation (8) supposing that the heat transfer remains 1D at the center of the heating element.

For each composition, 3 specimens were measured, in order to obtain an average

3. RESULTS AND DISCUSSIONS

3.1. Mechanical results

We first present the density before compressive strength.

3.1.1. Density

In the case of panels based on powdered typha leaves and various binders such as starch and gum arabic, we observe an increase in the density as a function of the binder content. The increase of the binder content in the formulation of typha panels obviously implies the increase of the density. The density varies respectively from 387 kg / m^3 to 492 kg / m^3 for starch and from 459 kg / m^3 to 500 kg / m^3 for gum arabic, when the mass concentration of binder varies from 33.33 % to 50 %. Comparing, it is unambiguously noted that the density is very small in the case of starch than in the case of gum arabic. The gum arabic panel is 1.17 times more daring than the starch-based one, for 33.33 % binder. This remark can easily be explained by the fact that the density of starch is lower than that of gum arabic. These results are comparable to the hemp concrete [8] whose density varies from 250 to 660 kg/m^3 depending on the percentage of binder (10 % to 40 %). We can conclude that the nature of the binder influences the variation of the density of typha panels.

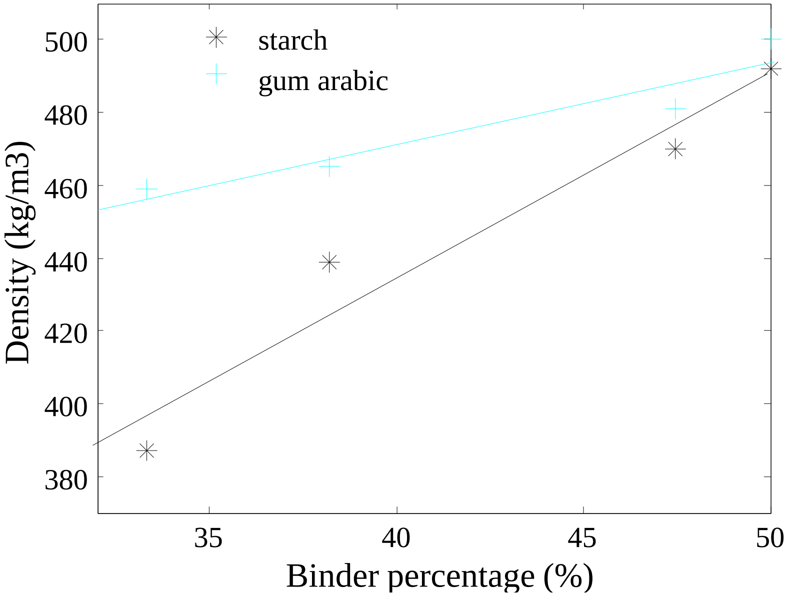

Figure 7. Density of typha - starch and typha - gum arabic panels according to the percentage of binder

3.1.2. Compressive strength

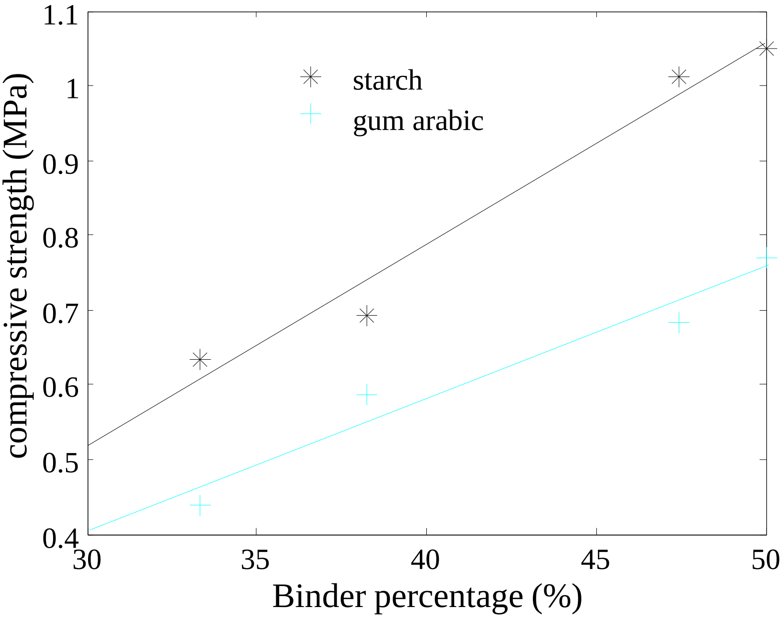

Figure 8. Curve of variation of the compressive strength of typha - starch and type gum arabic panels, as a function of the percentage of binder

Concerning the typha-starch and typha-gum arabic panels, we observe a quasi-linear evolution of the compressive strength in function of the mass content of binder as illustrated in Figure. 8. We observe an increase of 0.63 MPa to 1.05 MPa for starch and 0.44 MPa to 0.77 MPa for gum arabic as a function of the mass content of the binder. The level of mechanical performance of the panels depends on the thickness of the layer of binder coating the particles. These results show that the nature of the binder influences the mechanical behavior of the panels and those based on starch have better results. They are comparable to the compressive strength of hemp-starch concrete ranging from 0.1 MPa to 0.8 MPa [9]. We note that the typha-starch board, for 50 % binder, shows good resistance. The typha - starch board is 1.36 times stronger than the typha - gum board. Its compressive strength is higher than that of hemp-starch concrete with a strength of 1.05 MPa compared to 0.8 MPa.

3.2. Thermal results

3.2.1. Thermal conductivity

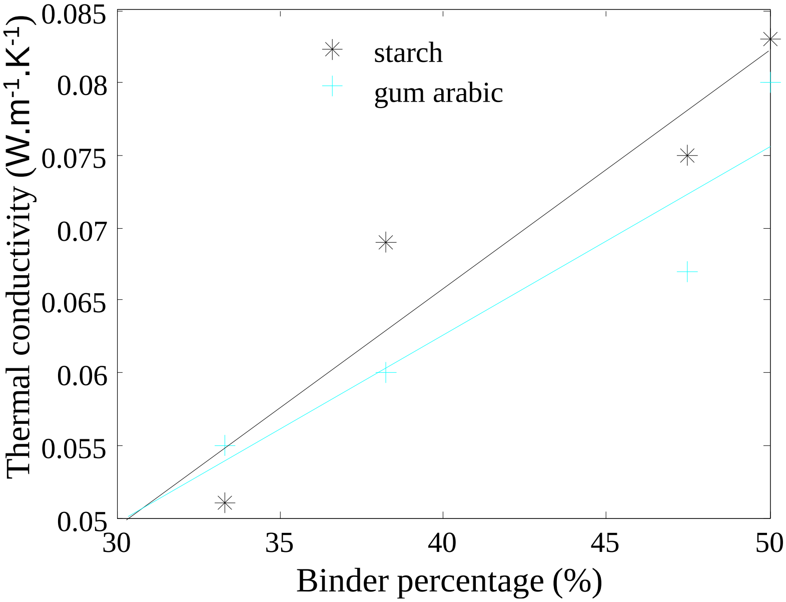

Figure 9. Thermal conductivity of dry panels of typha - starch and typha - gum arabic, depending on the percentage of binder

For different types of binders used, the variation of the thermal conductivity of the panels as a function of the binder content is illustrated in Figure. 9. Regarding the same type of fiber, for the different binders used such as starch and gum arabic, we note that the thermal conductivity of the panels differs from one binder to another as shown in Fig. 9. We observe a quasi - linear increase in thermal conductivity. The thermal conductivity values of the typha - starch and typha - gum arabic panels are respectively 0.051 $W.m^{-1}.K^{-1}$ to 0.083 $W.m^{-1}.K^{-1}$ and 0.055 $W.m^{-1}.K^{-1}$ to 0.08 $W.m^{-1}.K^{-1}$. These results show the effect of the binder on the thermal conductivity; Gum arabic panels have better insulation properties than starch-based panels. The best thermal conductivity is obtained with the typha-starch board (0.051 $W.m^{-1}.K^{-1}$) for 33.33 % binder (comparable to hemp-starch [9]). This values are close to the thermal conductivity range of many insulating materials such as wood-fiber insulation boards, used for thermal insulation in roofs, walls and floors. Likewise, the thermal conductivity values of panels are close to or lower than many of natural insulating materials like: jute (0.0482W.m^{-1}.K^{-1} [20]), hemp (0.06858W.m^{-1}.K^{-1} [21]) and date palm fibers (0.177 W.m^{-1}.K^{-1} [22]).

The results obtained show that the conductivity of the panels is significantly influenced by the mass content of the binder. This can be explained by the fact that, the larger of the binder dosage, the larger of the typha particles are embedded by a binder matrix reducing their insulating capacity. Increasing the dosage of the binder increases the density of the materials. The higher the density, the higher the thermal conductivity.

3.2.2. Thermal effusivity

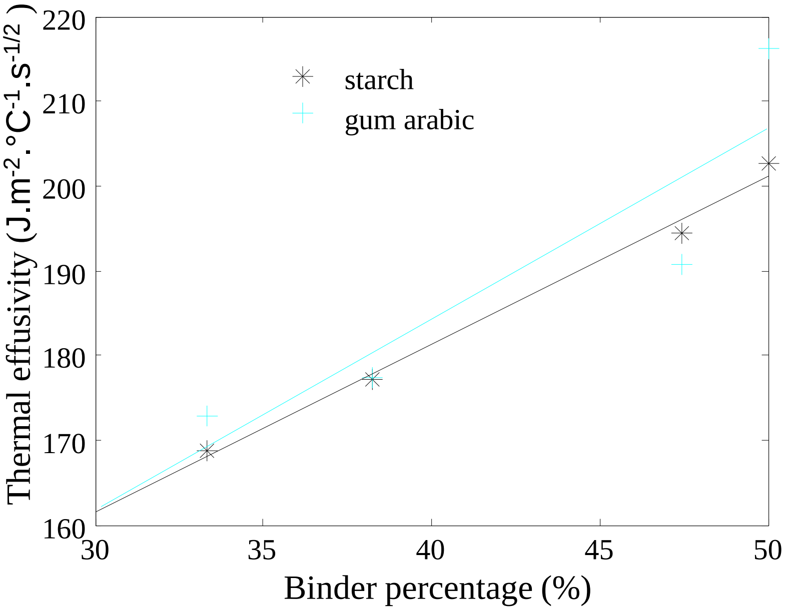

Figure 10. Thermal effusivity of typha - starch and typha - gum arabic panels, depending on the percentage of binder

The influence of the type of binder on the thermal effusivity of the panels is shown in figure. 10. The type of binder used affects the thermal effusivity of boards. We observe a quasi - linear evolution of the curves as a function of the binder content. The values of the thermal effusivity of the panels of typha - starch and typha - gum arabic are respectively 168.7 $J.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ to 202.7 $J.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ and 172.8 $J.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ to 216.2 $.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ .By comparing the different results, we deduce that the nature of the binder influences the values of the effusivity of the panels. Results show that the typha - gum arabic boards are more effusive. The values obtained are comparable to those of hemp concrete - lime of 206.9 $J.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ for a dry density of 413 kg/m^3 [23] and 267 $J.m^{-2}.{}^{\circ}C^{-1}.s^{-\frac{1}{2}}$ for ρ_{seche}= 440 kg/m^3 [24]. It should also be noted that the typha - starch and typha - gum arabic panels are more effusive than the hemp -

starch concrete [25] whose thermal effusivity values vary by $165.5 J.m^{-2}.°C^{-1}.s^{-\frac{1}{2}}$ to $197.5 J.m^{-2}.°C^{-1}.s^{-\frac{1}{2}}$.

4. CONCLUSION

This study allowed us to develop 100 % plant-based on thermal insulation panels made from typha plant and starch and gum arabic binders, for a possible use in the building. The influence of the nature of the binder on the thermal and mechanical properties has also been studied.

It has been shown that the mechanical behaviour of typha panels is strongly influenced by the dosage and the nature of the binder. The panels are comparable to hemp concrete but have low mechanical characteristics compared to traditional building materials. Starch-based panels show better results (1.05 MPa for 50 % starch).

The results showed that typha panels have a good thermal insulation capacity which depends on the dosage and the nature of the binder and also on the nature of the fibers. The resulting agro materials such as typha - starch and typha - gum arabic panels have a better insulating capacity and are comparable to hemp - starch concrete. According to the results of the thermal conductivity of the panels, the 33.33 % typha - starch composition of binder content with a density of 387 kg / m^3 has the best thermal insulation capacity with 0.051 $W.m^{-1}.K^{-1}$. The panels have low thermal effusivities so that they have low thermal inertia.

It would be interesting also in perspective to study various parameters such as vapor permeability, the hygroscopic properties of the panels, the durability (degradation phenomena involved in accelerated aging in a humid atmosphere or immersion in water), the porosity, the fire resistance of the material and simulate thermal and mass transfers within the panel.

Acknowledgements

We thank the Coordinator of the Project of Thermal Insulation Material Production to base of Typha in Senegal (PNEEB / TYPHA) and the director of the Applied Energy Laboratory (LEA).

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