SB&WRC Project

Technical Fact Sheet: Prototype 1 made from maize pith

June 2019

Abstract of the project

The SB&WRC *(Sustainable Bio&Waste Resources for Construction)* project, an undertaking of more than two years, aims to conceive, produce and test three innovative, low-carbon, thermal insulation materials from agricultural co-products and recycled waste. The project is supported by the development program Interreg VA France (Channel) England and its budget, estimated to be 1.8M€, is co-financed by the ERDF (European Regional Development Fund) for 69% (1.26M€ contribution).

This project, led by Nomadéis, is carried out by a cross-channel partnership which gathers academic research laboratories, private research and consulting companies, manufacturers and professional non-profit organisation of the building sector:

- Nomadéis;
- Veolia Propreté Nord Normandie;
- University of Bath;
- Ecole Supérieure d'Ingénieurs des Travaux de la Construction de Caen (ESITC Caen);
- Construction21;
- UniLaSalle;
- University of Brighton;
- Alliance for Sustainable Building Products.

Unilasalle
https://www.unilasalle.fr
Project team:
Hafida ZMAMOU, R&D Engineer
Feriel BACOUP, R&D Engineer
Angélique MAHIEU, lecturer-researcher
Richard GATTIN, lecturer-researcher

Nomadéis
www.nomadeis.com
Directors:
Cédric BAECHER, Cofounder and Associate Director
Nicolas DUTREIX, Cofounder and Associate Director

Summary

The present report synthesises the experimental results obtained for Prototype 1 which is a thermal insulation material made from maize corn within the SB&WRC project. The production process of this prototype is straightforward as it implies, mostly, to mix maize corn and water and to compress at high temperature to obtain a particleboard. The thermocompression process is a usual process in the sector of panel manufacturing.

The choice of maize pith has been made for many reasons. Several authors reported that bio-based insulation materials made from crop by-products are an interesting alternative to those obtained from fossil energy. They have lower thermal conductivity and density, are cheaper, available in abundance and environmentally friendly compared to conventional ones (Ashori et al., 2014). In this context, low-density particleboards were developed from a combination of crop by-products and natural binders to have potential application for ceiling panels, core materials, and bulletin boards (Wang et al., 2002). For the maize pith, the internal part of the maize stalk, the separation process to obtain the pith, exists at industrial scale, the valorization chain is to be developed by diversifying outlets. This agricultural by-product presents a very high potential of valorisation for agromaterials.

Experimental tests on this material have shown that it has potential and may be considered as a good thermal insulant with a lambda value of approximately 0,042 $W.m^{-1}.K^{-1}$ which is essentially similar to that of industry standards such as glass or rock wool, whose thermal conductivity is around 0.04 $W.m^{-1}.K^{-1}$.

Table of Contents

1. From resource to prototype

1.1 Maize pith

At the beginning of the SB&WRC project, we selected several by-products (maize stalks and rape straw). After a phase of tests we decided to continue working solely with maize pith (Figure 1). The maize pith, came from the East of France and is supplied by Cormo Enterprise which holds the patent for the bespoke separation process.

Figure 1: Photograph of the maize stalk (left picture) and of the maize pith after separation

1.2 Prototype manufacturing process

Particleboards are made with particles of maize pith without any binder addition. The quantity of matter used was calculated in order to obtain panels with different density between 25 to 100 kg.m^{-3}. The pith particles blended with water (40% mass/plant particles mass) were thermocompressed during 15 minutes on each side of the panel at 190°C. Chocks are utilized to stop the closure of the mould in order to obtain a fixed panel volume and thus the target density. The size of the particleboard was 300*300*28 mm^3.The different steps of the prototype 1 manufacturing are illustrated in Figure 2.

Figure 2: Illustration of the different steps of the prototype 1 manufacturing process

The prototype 1 consists of three layers (Figure 3) : the thickest layer with a density of 50 Kg.m^{-3} and the two thinnest layers with a density of 400 Kg.m^{-3}.

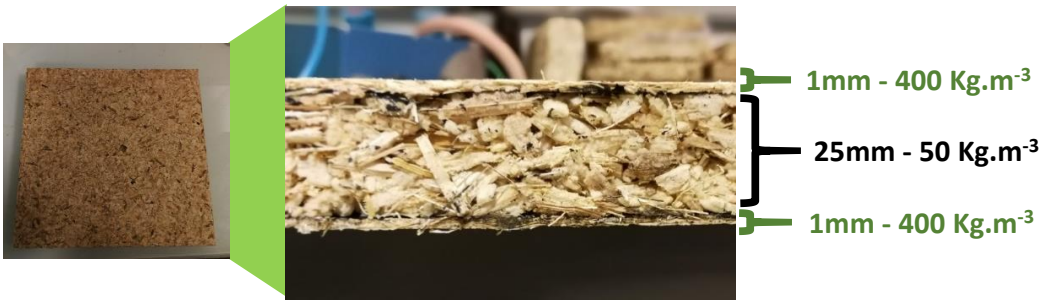


Figure 3: Illustration of the three-layer panel

2. Properties of the resource

2.1 Densities

2.1.1 Experimental procedure

Bulk density

The measurement of bulk density consists in weighing aggregate and measuring the corresponding volume with water. The tapped density method is generally more useful and can be measured according to Amziane et al. (2017). After sampling, the quantity of the material for one measurement should be adjusted to be half the volume of the cylindrical mould intended to be used to measure the bulk density.

Specific density

Specific density was determined by using helium pycnometer. This method enables the precise measurement of the sample's volume. It consists in introducing helium into a reference chamber with a known pressure and then allowing it to expand into the chamber containing the sample. The drop in pressure in the reference chamber is then measured. The sample volume may then be determined according to Mariotte's law:

$$V_s = V_c - \frac{P_2 - P_a}{P_1 - P_a} V_2$$

whereby:

- P_1: gas pressure in the reference chamber (Pa);
- P_2: gas pressure in the expansion chamber (which contains the sample) (Pa);
- P_a: atmospheric pressure (Pa);
- V_2: expansion volume (cm^3);
- V_c: chamber volume (cm^3);
- V_s: sample volume (cm^3).

Specific density is then given by the following equation: $\rho_b = \frac{m_s}{V_s}$, with ρ_b being the density and m_s the sample's mass.

2.1.2 Experimental results

Bulk and specific densities

The results of bulk and specific densities are given in the following table. The values for each analysis transcribed in Table 1 represent an average of 3 measurements.

Table 1: Bulk and specific densities of the maize pith (Kg.m-3)

Bulk density	Specific density
15 ± 0,3	1254 ± 24

The SEM analysis permits the observation of the honeycomb structure of the maize pith, the presence of fibres traversing the maize pith (Figure 4).

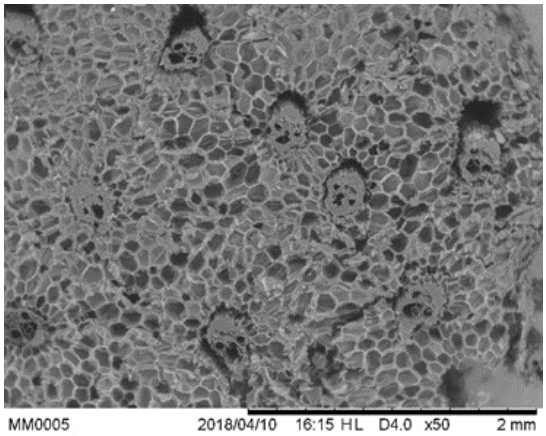


Figure 4: SEM picture of the maize pith

2.2 Particle size distribution

2.2.1 Experimental procedure

The test consists of dividing and separating a material into several particle size classifications of decreasing sizes by means of a series of sieves. The aperture sizes and the number of sieves are selected in accordance with the nature of the sample and the accuracy required. The particle size distribution of the maize pith was measured in the material's dry state following the guidelines of the Rilem TC BBM.

2.2.2 Experimental results

The results of particle size distribution are given in the figure 5.

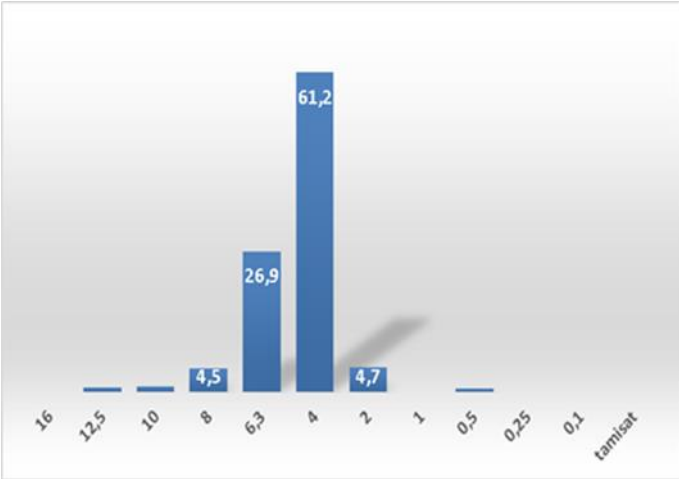


Figure 5: Particle size distribution for the maize pith [%]

2.3 Moisture and hydric properties

2.3.1 Experimental procedure

Water absorption

This test is derived from an experimental protocol developed by the RILEM TC 236-BBM group. The procedure used to measure the water absorption of the different materials is as follows:

1. Dry the sample at 40°C until a mass variation lower than 0.1% is obtained over a 24 hours period;
2. Immerse completely a plastic micro-perforated bag in water;
3. Place and attach the bag in a centrifuge and let it turn for 30 seconds at 500 RPM, then note the bag's mass;
4. Weigh the mass (M_0) of the material and place it in the bag;
5. Immerse completely the bag filled with the material in water for 5 minutes;
6. Take the bag out of the water, place it in the centrifuge and let it turn for 30 seconds at 500 RPM;
7. Weigh the spin-dried bag and note the mass M_1 (5 min);
8. Repeat steps 5, 6 and 7 for other samples for different immersion durations;
9. Calculate the water absorption according to the following equation:

$$M(t) = \frac{M_t - M_0}{M_0} \,.100$$

Sorption-desorption isotherms

The gravimetric method can be used to determine the sorption capacity of a material. After drying at 50°C, the straw is placed in different relative humidity values (first increasing and then decreasing) while keeping a constant temperature. The moisture content of the material is calculated for each step. This is done with the Dynamic Vapour Sorption device (DVS), using the same procedure as Hill et al. (2010).

2.3.2 Experimental results

Water absorption

The results of water absorption are given in the following figure.

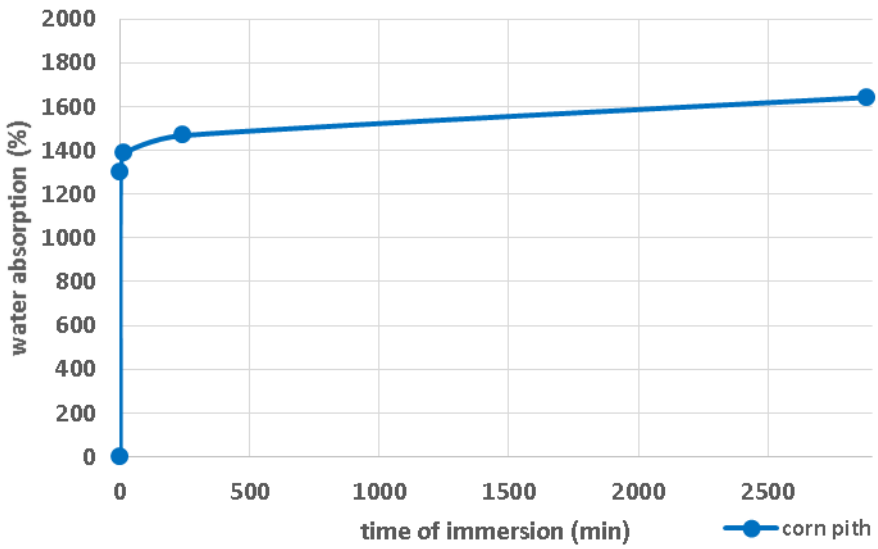


Figure 6: Water absorption for the maize pith [%]

Sorption-desorption isotherms

The results of water absorption are given in the following figure.

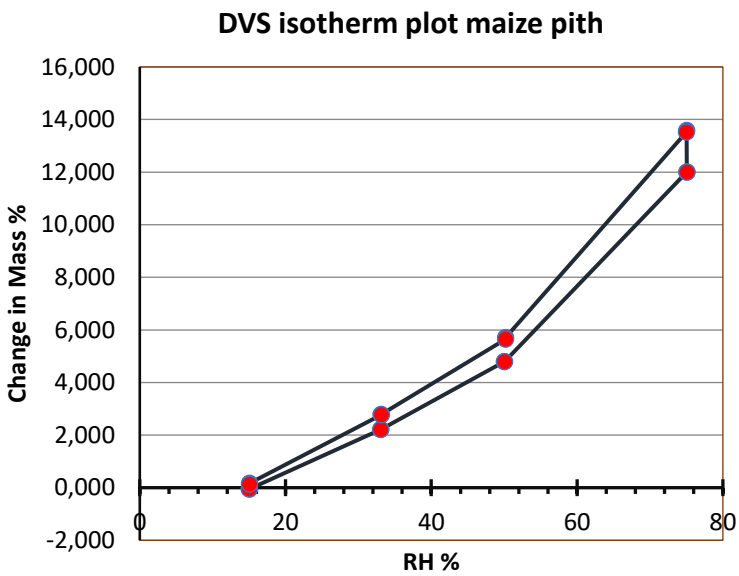


Figure 7: Maize pith isotherm

2.4 Biochemical Composition

2.4.1 Experimental procedure

The first extraction is realized with NDF (Neutral Detergent Fiber) solution, in the FibertecTM 8000 Automated Fiber Analyzer to remove soluble cell contents. ADF (Acid Detergent Fiber) solution is used for the second extraction. The last extraction is done with ADL (Acid Detergent Lignin) solution which is 72% sulfuric acid. After each extraction, the porous bags are rinsed in water, hed with acetone and dried overnight at 105°C. Then, the samples are calcinated at 480°C for 3 hours.

2.4.2 Experimental results

The results of biochemical composition are given in the following figure.

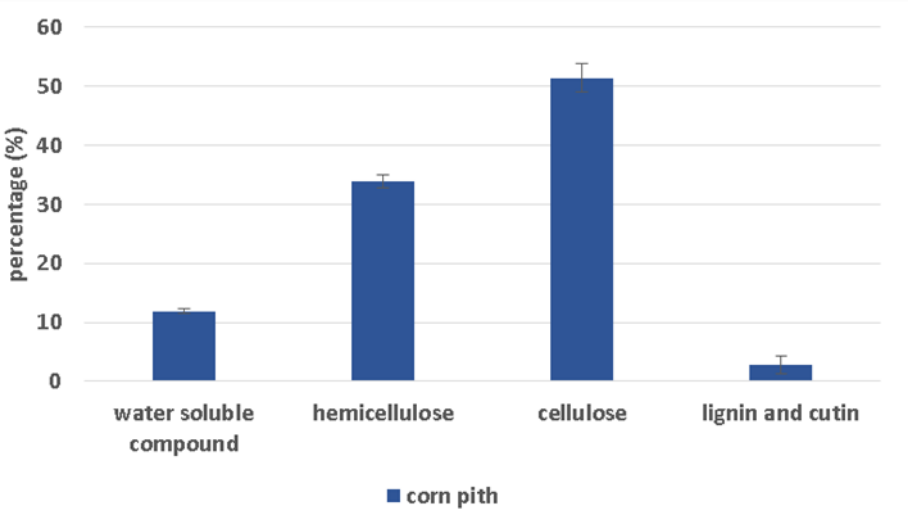


Figure 8: Biochemical composition for the maize pith [%]

The study of the biochemical composition and molecules in plant cell surface may help to better understand the impact of the chemical interaction between pith particles during the manufacturing process of particleboards.

3. Hygrothermal properties of the prototype

3.1 Thermal conductivity

3.1.1 Experimental procedure

The thermal conductivity of the particleboards was measured with a Heat Flow Meter HFM 436 Lambda from Netzch. The sample size was 150*150*25 mm^3. The measurements were performed in a steady state at 20°C with a temperature gradient between the hot and the cold plate of 20°C and repeated at least 3 times for each material.

3.1.2 Experimental results

The results of thermal conductivity as a function of the density are given in the following figure.

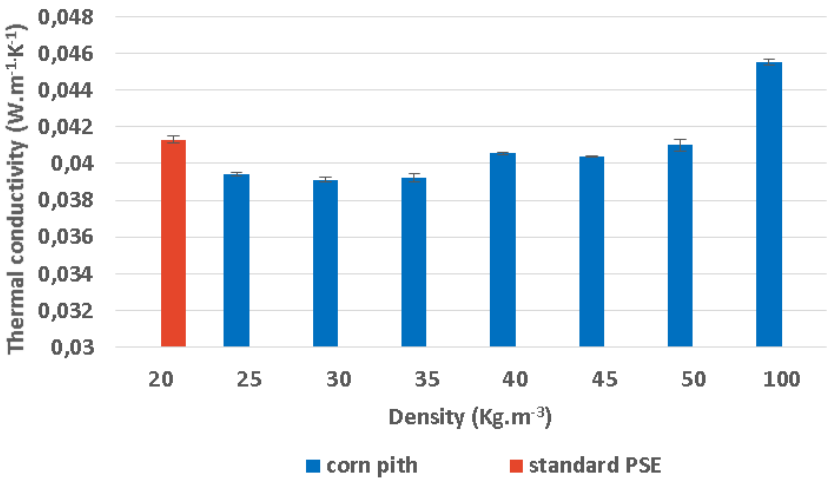


Figure 9: Thermal conductivity of maize pith panels

All the studied panels present interesting thermal conductivities in comparison with classical polystyrene panel (standard PSE) which present a thermal conductivity of 0,041 $W.m^{-1}.K^{-1}$.

3.2 Adsorption-desorption (Moisture Buffer Value)

3.2.1 Experimental procedure

The Moisture Buffer Value (MBV) ($g.m^{-2}.\%RH^{-1}$) is the one surface of the material exposed to a cyclic relative humidity which allows to assess a regular moisture adsorption-desorption content per unit of surface

Parallelepipeds of maize pith panels (65*85*25 mm^3) were placed in the Dynamic Vapour Sorption after conditioning at 23°C and 50%RH until stable mass was recorded. The mass of the parallelepipeds was recorded and then placed under the conditions stated in Table 2.

Table 2: Chamber settings

Humidity conditions at 23 °C	Relative humidity (%)		
	Preconditioning	Moisture adsorption	Moisture desorption
		Step 1	Step 2
	50	75	33

The samples were placed in the dynamic vapour sorption prior to cycling through a period of 8 hours at 75% RH and a period of 16 hours at 33% RH for a total of five cycles.

3.2.2 Experimental results

The Moisture Buffering Value can be subsequently calculated as **1.14 g/m2·Δ%RH** for the maize pith panel.

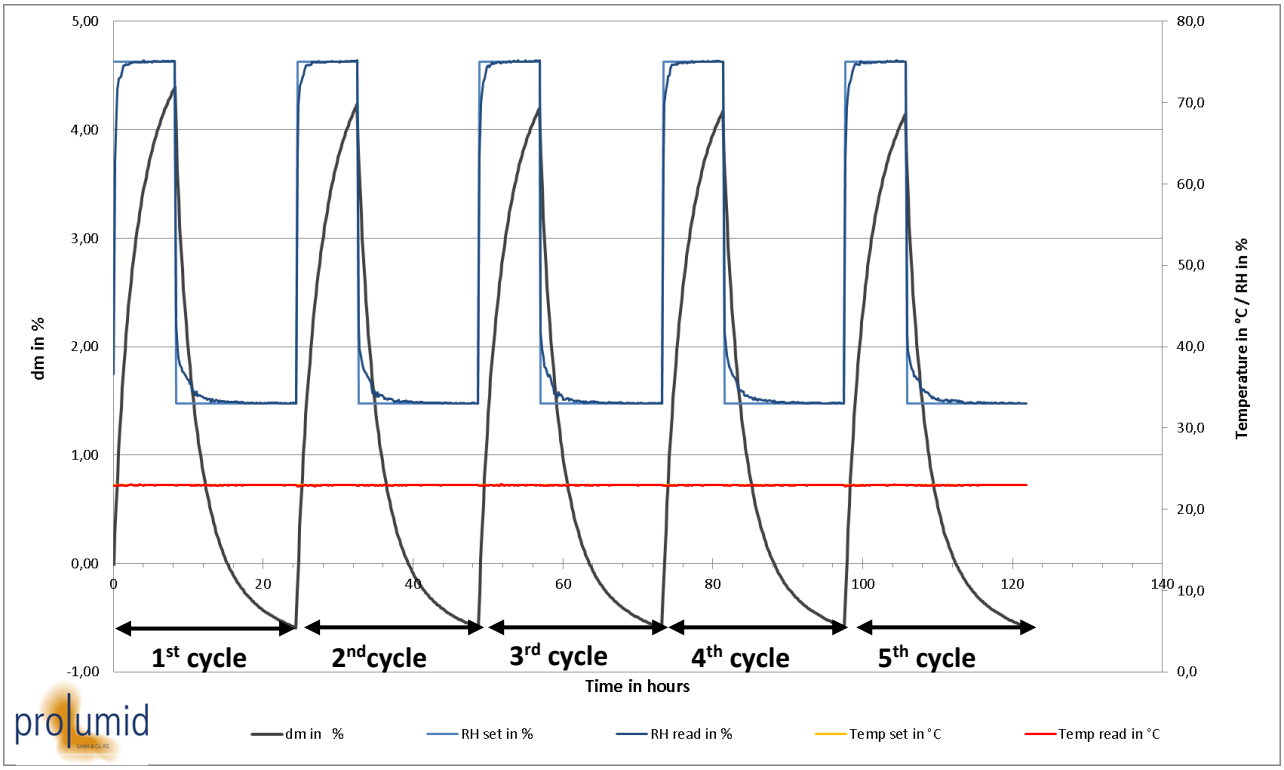


Figure 10: Moisture adsorption/ desorption over time for maize pith panel

4. Mechanical properties of the prototype

4.1 Three-point bending

4.1.1 Experimental procedure

Three-point bending tests were carried out on each particleboard with a universal mechanical properties testing machine equipped with a load cell of 200 N with a precision of 0.1%. A constant speed of 6 mm/min was applied on the central cylinder and the required force to deform the sample was measured up to failure. The sample dimensions were 150*30*25mm^3.

4.1.2 Experimental results

The table 3 presents the maximal bending strength for the maize pith panel and the reference expanded polystyrene.

Table 3: Three-point bending tests for maize pith panel

	Maize pith panel	Expanded polystyrene
Maximal bending strength (MPa)	0,03	0,17

5. Fire resistance of the prototype

5.1 Method for testing of ignitability

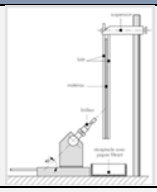
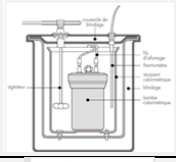
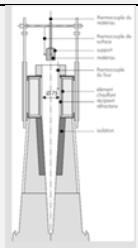
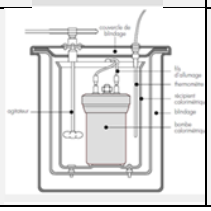
5.1.1 Experimental procedure

A wildfire is an uncontrolled fire which, by spreading rapidly and uncontrollably, causes significant damage. Most fires are created by the combination of three elements: a fuel, an oxidizer and a source of energy also known as the «fire triangle».

To limit the damage caused by fires, the regulations on the fire safety of buildings have a number of requirements, particularly in terms of choice of materials. The role of building materials during a fire assessed through the following measures: (i) the fire reaction of the material, i.e. its behavior of materials during the first phases of the fire, the ease of ignition & (ii) fire resistance.

Since 2002, construction products for which a classification is mandatory, have to undergo a series of tests that simulate the first three phases of the development of a fire to obtain their reaction to fire classification. Existing tests corresponding to the three development phases are illustrated and are summarised in Table 4:

Table 4: Simulation of fire phases and associated tests

	Tests realized		Principe	classification categories
Starting of test	Method for testing of ignitability		Punctual attack at the small flame on a sample of material being arranged vertically	B, C, D, E and F
Starting of Fire	Test single Burning Item (SBI)		attack with inflamed object with measurement of temperature and oxygen and carbon dioxide concentration	A2, B, C and D
Complete inflammation	ISO oven test		Flammability test on a sample exposed vertically in oven at 750°C during 60 minutes	A1 or A2
	calorimetric test		Measurement of the higher calorific value	A1 or A2

When all these tests are carried out, a classification letter is attributed to the material according to the following European classification (Table 5):

Table 5: European fire reaction classification

A1	No contribution to fire
A2	Very low contribution to fire
B	Low fire contribution
C	Significant contribution to fire
D	High contribution to fire
E	Significant contribution to fire
F	Very important contribution to fire
NPD	No behavior in response to determined fire

According to the NF EN ISO 11925-2 standard, the small flame ignitability method corresponding to the first phase for development of fire (described in standard EN 13501-1). It consists in placing a sample of the prototype in a chamber test (Figure 1), and apply a 2cm propane flame for 15 seconds on the lower surface of a sample of material. This test give us some information about the capacity of a material to ignite more or less quickly in contact with a flame. After removal of the burner, a visual observation can determine if there is inflammation and the time during which the persistent flame has exceeded the height set by the standard to 15 cm. The presence of any inflamed droplets should be noted.

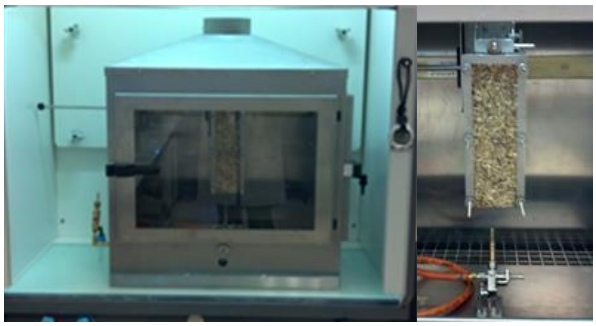


Figure 11: Fire test chamber (left) sample before test (right)

According to the NF EN ISO 11925-2 standard, materials having a degradation zone inferior to 15cm and not producing inflamed droplets are considered to have good resistance to ignitability.

5.1.2 Experimental results

The small flame ignitability method for prototype 1 and for a commercial polystyrene reference was carried out at UniLaSalle. The results of this test are summarised in the following table 6.

Table 6: European fire reaction classification

Material	Prototype 1	Commercial polystyrene for reference
Sample before a test		
Sample after 15 seconds in contact with small flame		
Height of damage area	Superior to 15 cm	Superior to 15 cm
Total destruction time of the sample	45 minutes	15 seconds
Droplet production	No	Yes

The observations made during these first tests show that after removal of the burner, the damaged area is greater than the 15 cm recommended by the standard for both materials. In addition, particles remain incandescent and progressively consume the sample of prototype 1 until complete destruction after 30 minutes. On the other hand, no inflammation or droplet production is observed.

The tests for the commercial reference of polystyrene demonstrate an immediate inflammation of the sample with droplet production. The sample is totally destroyed in 15 seconds.

At the end of this first test, the prototype 1 as well as the polystyrene commercial reference are classified E. According to NF EN ISO 11925-2 standard, they contribute significantly to fire. However, this test also highlights the interest of the use of crop by-products material in insulating panels because the resistance of the crop by-product board before total combustion is significantly higher than that of the polystyrene board. As weather is a crucial parameter during a fire, this saving of time is therefore a major asset for particles boards.

6. Biodegradability of the prototype

6.1 Compostability method

6.1.1 Experimental procedure

The end of life of biobased materials is still poorly known, due to the recent nature of the deployment of this type of material in buildings. However, a study carried out by ADEME estimates the arrival of the first bio-based insulation materials in the end-of-life sectors as early as 2020. In the context of material recovery processes, manufacturers are looking for simple, pragmatic and practical solutions and economically viable.

Composting method is a process on an industrial scale that represents a solution for the sustainable management of agricultural byproducts. It is one of the fastest ways of transforming biowaste into a kind of humus, a stable material that can return to the soil as an organic amendment, thus completing the cycle of organic matter and to bring a beneficial effect taken into account in the context of a LCA, related to the ecosystem service (biodegradation) rendered by microorganisms degrading materials.

The compostability of a material is defined by a standard ISO 14855 and realized in laboratory (Figure 12), which measures the amount of CO_2 produced (mineralization phase) by microorganisms during the compost biodegradation process.

Figure 12: Biodegradation system

Many research studies is being done on the behaviour of different crop by-products, such as those studied in the SB&WRC project (wheat straw, rapeseed and maize straws), and highlight their compostability and agronomic value.

6.1.2 Experimental results

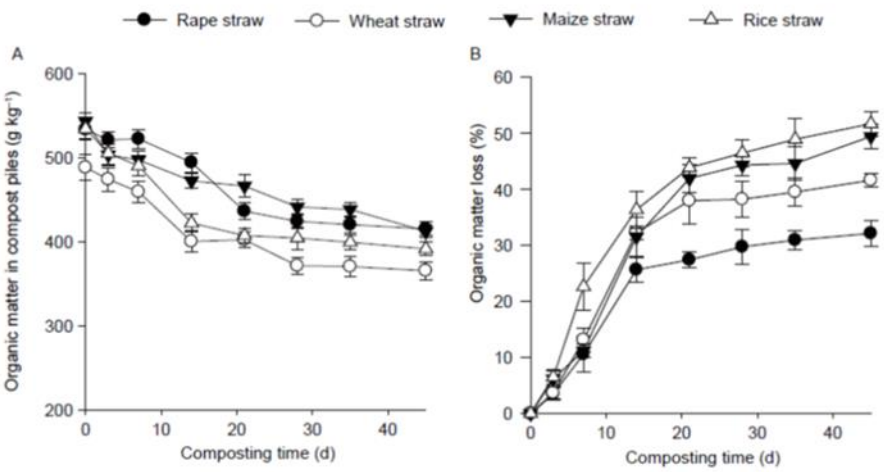


Figure 13: Study of Agricultural residues composting (Xiu-Lang et al., 2016)

Regarding the prototype 1 obtained from corn-pith, we can rely on these bibliographic elements to confirm their compostability and the interest of continuing studies on the development of a composting industry for the end of life of these materials. However, it is important also to verify that the conditions and process of formulation chosen for the material has no effect on its biodegradation. Recent research conducted at UniLaSalle shows that the thermocompression process in a context of direct return to the soil does not impact the biodegradation of the material obtained. This thesis entitled "Decomposition on soils of crop residues and

bio-sourced materials: impact on microbial communities of agricultural soils and associated functions" studied the return of a material such as prototype 1 to soil, but with the sunflower-pith.

This type of approach can be gives for the material the possibility to close the carbon cycle, in a logic of circular economy, by the degradation of the carbon sources contained in agro-resources or agricultural by-products. Including a deconstruction and sorting adapted, this approach, already common for some products such as packaging labelled OK compost and it is still experimental in the building sector but could open new perspectives.

7. General discussion

In summary, the results of the various experiments presented in the report showed that maize pith can be used with advantage in manufacturing particleboards without binder. Insulation properties of the particleboard studied are interesting, with thermal conductivities near to commercial reference, expanded polystyrene. The maize pith prototype offers further benefits through hygroscopic performance and indoor air quality through buffering internal relative humidity levels. Further research is still required to improve mechanical properties and to study the durability.

8. References

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