2nd International Conference on Bio-based Building Materials &
1st Conference on ECOlogical valorisation of GRAnular and FIbrous materials

June 21th - 23th 2017
Clermont-Ferrand, France

IS HEMP LIME CONCRETE A MIX OF HEMP AND LIME?

B. Mazhoud, M. Viel, F. Collet, A. Phelipot-Mardelé, C. Lanos*, S. Prétot

Laboratoire de Génie Civil et Génie Mécanique, Equipe Matériaux Thermo Rhéologie, Rennes, France

*Corresponding author ; e-mail: christophe.lanos@univ-rennes1.fr

Abstract
Hemp lime concrete is a mix of hemp shiv glued in a mineral binder. Such concrete is characterized by low thermal conductivity and interesting hygric properties. The aims of this study realized in the frame of ISOBIO Project is to understand which is the contribution of each component of the hemp lime concrete to the thermo-hygric properties of the mix. The study focuses on the case of a commercial hemp shiv (Biofibat®, CAVAC France) and a lime based binder (ThermO®, BCB). The measurement of thermal conductivity and Moisture Buffer Value are performed on some conventional hemp lime concrete formulations. On the other hand, the same measurements are performed on hemp shiv alone (at different density) for several grading showing that thermal Conductivity and MBV evolves according to the density. The last measurements are realized on samples realized with ThermO® lime matrix foamed to achieve sufficiently low densities ranging from 500 kg/m^3 to 1100 kg/m^3. The comparison of results obtained on each component and on mixes for the same range of density is full of interest to evaluate occurrence of a synergetic effect, or not. The data are used to adjust a model useful for the optimization of the mix proportioning.

Keywords:
Hemp shiv; foamed lime, thermal conductivity, Moisture buffer value.

1 INTRODUCTION

This study is realized in the frame of EU ISOBIO Project. This project deals with the valorization of various kinds of bio-sourced aggregates in the formulation of new building materials. The expected properties are a sufficient thermal insulation and an acceptable ability to damp the moisture variations. The tested raw materials are shiv from wheat straw, hemp flax and corn cob. The reducing of embodied energy and the limitation of global energy consumption, whilst leading to the best hygrothermal comfort for the user, are the main objective of the project.

The formulation of concrete, mixing biosourced aggregates and a mineral binder, constitutes an interesting solution to produce composites. Traditional hemp concrete is a mix of hemp shiv with a hydraulic or air slaked lime [Amziane 2013] [De Bruijn 2013] [Tran 2010]. Such mix presents a moisture permeability and a multi-scale pore size distribution, leading to interesting properties regarding thermal and moisture transfers [Collet 2013] [Collet 2014]. Hemp concretes present thermal conductivity ranging between 0.1 and 0.2 W/(m.K) for conventional densities. They are considered as excellent hygric regulator with a moisture buffer value (MBV) higher than 2 g/(m².%RH).

The aim of the work is to understand which is the contribution of each component of the hemp lime concrete to the thermo-hygric properties of the mix. Samples are produced with binder alone, hemp shiv alone and hemp lime concrete. The studied properties are the thermal conductivity and the moisture buffer value. Comparison of the results is based on the analysis of the influence of the porosity on the performances. To make easy the interpretation, the same range of density is expected. In the case of samples made with binder alone, a foaming method is used to master the density.

2 MATERIALS AND METHODS

2.1 Binder

The lime based binder ThermO® from BCB is a dedicated formulated lime for hemp lime concrete.

Its specific density is 2560 kg/m^3 measured by Le Chatelier pycnometer method, at room temperature. Its chemical composition is determined by Atomic Fluorescence Spectrometry method with a Niton XL3T GOLDD+ (Fundis Technique). Results are shown in *Tab.* ***30***.

2.2 Shiv

The used hemp shiv are commercial products Biofibat® and 3 others products from CAVAC, France. Different characterization tests were performed in laboratories. They include among others: bulk density, water absorption and particle size distribution using

two methods: mechanical sieving and image analysis. The characterization is performed following the recommendation of RILEM Technical committee [Amziane 2017].

Tab. 30: Chemical composition of lime-based binder (mass %)

Material	Lime-based binder (ThermO®)
Si	4.306
Mg	0
Al	0.972
S	1.125
Cl	0.112
K	0.465
Ca	48.242
Ti	0
Fe	0.730
Others	43.941

Before determining bulk density of the bio-aggregates, they are dried in an oven at 60 °C until a mass change less than 0.1 % between three successive weighings with 24 h time steps. The bulk density of hemp shiv was measured at room temperature (21 ± 2°C). A glass cylinder of 10 cm in diameter and 20 cm in height and a balance accurate to 0.04 g were used. The glass cylinder was filled with dry shiv to about half the height of cylinder. The level was marked after up-ending the glass cylinder ten times, and the corresponding volume was measured with water.

The bulk density of the hemp shiv is determined by the equation (1):

$$\rho_{HS} = \frac{M_S}{M_W}\rho_W \quad (1)$$

ρ_{HS}: Bulk density of Hemp shiv, kg/m^3,

M_S: Mass of dry hemp shiv, g,

M_W: Mass of water corresponding to dry hemp shiv, g,

ρ_W: Density of water, 1000 kg/m^3.

The bulk density of hemp shiv was the mean value of the measurements made on ten different dry samples (*Tab.* ***31***).

The results obtained on studied hemp shiv are between 101 and 113 ± 2 kg/m^3. These values are within range of values found in the literature [Arnaud 2012] [Nozahic 2012b]. The specific density of hemp shiv is measured by pycnometer method after a meticulous milling process; the mean value is 1352 kg/m^3. The apparent density of a unique hemp shiv aggregate is determined thanks to the porosity of a unique shiv 0.78% (from [Cérézo 2005], confirmed by some measurements on particles). Therefore, the apparent density of a unique hemp shiv aggregate is 297 kg/m^3.

The particle size distributions of hemp shiv are analysed by using two methods (*Fig.* ***20***): mechanical sieving [AFNOR 1996] and image analysis [Amziane 2017]. The image analysis method has been done with ImageJ software and a colour scanner to analyse images scanned at 600 DPI. This method was carried out on the hemp shiv sample weighing around 3 to 6 g.

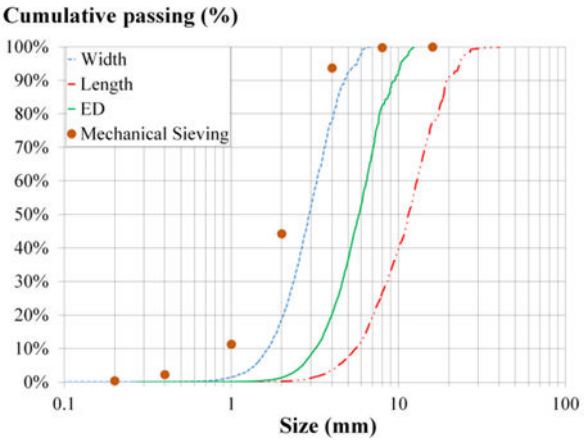


Fig. 20: Particle size distribution of Biofibat® shiv.

This figure indicates that the size distribution of hemp particles according to the width is very close to the distribution obtained by the sieve method. This result is in accordance with the literature [Nguyen 2010] [Nozahic 2012a] [Picandet 2012].

The results show that Biofibat® hemp particle size was distributed from 0.14 mm to 6.8 mm, from 0.6 mm to 40.6 mm and from 0.36 mm to 12.48 mm according to the width, length and equivalent diameter (ED) respectively. The mean width of particles is 2.9 mm and the mean length is 11.5 mm. Three other hemp shiv are obtained by sieving Biofibat® hemp. The bulk density, the mean width and mean length of all the hemp shiv are presented in table 2.

Tab. 31: Physical properties of studied hemp shiv

Material	Bulk density kg/m^3	Width mm	length mm
Biofibat®	107	2.9	11.5
HS 1	118	7.6	2.4
HS 2	101	7.7	2.1
HS 3	113	18.0	4.2

2.3 Moisture buffer value

The moisture buffer value MBV quantifies the moisture buffering ability of a material. It is measured according to the method given in the NORDTEST project [Rode 2005]. This project defines the practical moisture buffer value of materials: the amount of moisture uptake (and release), per open surface area, under daily cyclic variation of relative humidity (Eq. 2):

$$MBV = \frac{\Delta m}{A.(RH_{high} - RH_{low})} \quad (2)$$

With:

MBV: moisture buffer value, g/(m².%RH),

Δm: moisture uptake/release during the period, g,

A: open surface area, m^2,

$RH_{high/low}$: high/low relative humidity level, %.

The NORDTEST project leads to a classification of moisture buffer values from negligible to excellent (*Fig.* ***21***).

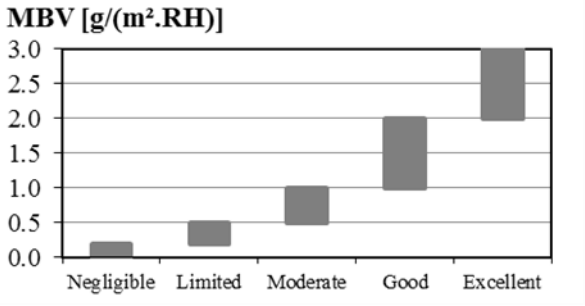


Fig. 21: Nordtest project Classification [Rode 2005].

After stabilization at (23 °C, 50 %RH), specimens are exposed to daily cyclic variation: 8 h at high relative humidity (75 %) followed by 16 h at low relative humidity (33 %). The test goes on until the change in mass Δm is the same between the last three cycles with less than 5 % of discrepancies. Thus for each specimen, the MBV is the average value calculated from the last 3 cycles.

The device used consists in a climatic chamber (VÖtsch VC4060) that can be controlled in the range +10 to +95 °C and 10 % to 98 %RH (*Fig.* ***22***). The switch in the chamber relative humidity (75 %RH; 33 %RH) is done manually according to the 8/16 h scheme. Temperature and relative humidity are measured continuously with sensor SHT75 and with sensor of the climatic chamber; the air velocity is measured in the surroundings of the specimens: about 0.1 m/s.

The specimens are weighed out of the climatic chamber five times during absorption period and two times during desorption one. The readability of the balance is at most 0.01 g, and its linearity is 0.01 g. The accuracy of the moisture buffer value is thus about at most 5 %.

The test method requires specimens which are sealed on all out one of the sides. The exchange area is higher than 100 cm² for each specimen, and the total exchange area is higher than 300 cm² by material, except for the mineral foams, where total exchange area is 100 cm².

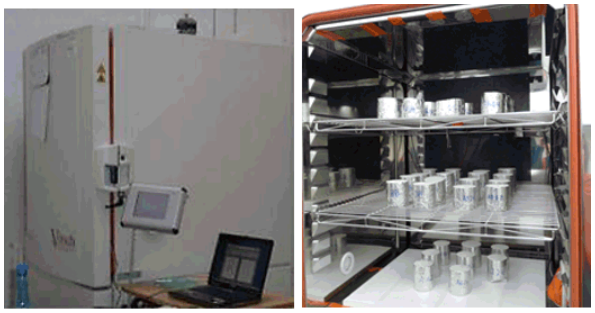


Fig. 22: Measurement of Moisture Buffer Value: experimental device and samples inside.

2.4 Thermal properties

The thermal conductivity was measured using the commercial CT-meter device equipped with 5 centimetres-length hot wire. The measurement is based on the analysis of the temperature rise versus heating time. The heat flow and heating time are chosen to reach high enough temperature rise (> 10°C) and high correlation coefficient (R^2) between experimental data and fitting curve (

Fig. ***23***). In this study, the power used ranges between 0.205 and 0.378 W and the heating time is 120 s. The thermal conductivity of a pair of specimens is the average of five values with a variation coefficient lower than 5 %. The thermal conductivity of one material is the average value of all measurements.

In order to measure the thermal conductivity at dry state, the specimens are dried until a constant mass is reached. Then, the specimens are conditioned at 23 °C using dry chamber. Prior to the test, the specimens are discontinuously weighed until a constant mass is reached (difference lower than 0.01 % for two consecutive weighing with 48 h time step).

Fig. 23: Measurement of thermal conductivity at dry state left: experimental thermogram, right: CT meter, hot wire and dry chamber.

2.5 Porosity

The porosity shall be highlighted as a property with an impact on moisture adsorption. However porosity is very complex to measure. Different types of voids form the porosity with pore size ranging from few dozen of Angstrom to few millimetres.

Three porosities are identified:

- p_T : total porosity which includes all the voids in the materials. This value is a calculated value. For mineral foam and hemp lime composite, the voids volume is based on the difference between the apparent fresh volume and the solid components volume. For hemp shiv, total porosity depends on bulk density and the specific density of hemp shiv.
- p_M : matrix porosity. This porosity corresponds to the inner voids volume of the matrix. For hemp shiv, it corresponds to the intra-aggregate air contained in hemp aggregates. For mineral foam, it corresponds only to voids inside the matrix, not the bubbles. They appear during the hardening and the material drying. For Hemp lime composite, it is more complex because voids linked to matrix porosity are inside the binder matrix and inside the shiv. Both have to be considered : $p_{M\text{-}HS}$ and $p_{M\text{-}B}$
- p_V: voids porosity. This porosity corresponds to air bubbles in the paste or between the particles. For mineral foam, voids are air bubbles due to the manufacturing process. For hemp shiv, it is the voids between each shiv, due to the particles arrangement. For hemp lime composite, once again, it is more complex, the voids volume corresponds to the voids due to the mixing of hemp

with lime paste. They depends on the bubbles in the paste and the arrangement more or less compact of the components.

The Eq. 3 links these three porosities together:

$$p_T = p_M + p_V \quad (3)$$

3 HEMP LIME COMPOSITE

This study investigates one composite produced by mixing Biofibat® hemp shiv with the lime based binder (ThermO® - BCB) with Hemp/Binder mass ratio 0.5. The Hemp/Binder mass ratio is estimated regarding traditional mix proportioning of hemp concrete used for wall [Construire en Chanvre 2007].

Fig. 24: Production process: a) Binder mixing; b) Hemp mixing by hand; c) Addition of the moist hemp and mixing; d) Compaction.

The hemp shiv (

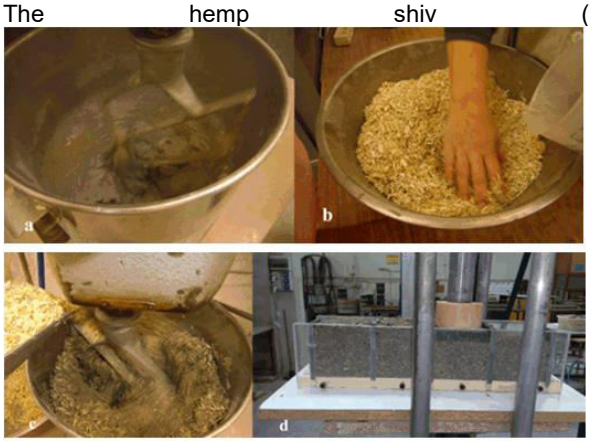


Fig. ***24***) was weighed and mixed by hand for about 2 min, in a container, with Water/Hemp mass ratio of 0.4. At the same time, dry binder and water are mixed to form a binder paste with Water/Binder mass ratio of 0.4. Progressively the moist hemp was added to the binder paste and mixing is continued for approximately 5 min until a homogeneous mix is obtained. The water content was chosen to obtain a suitable workability. Add of water leads to a W_{tot}/B ratio of 0.8.Then the mixture is placed in cubic moulds of 10 x 10 x 8 cm in 2 layers: each layer is compacted at 0.1 MPa using a universal testing machine [Construire en Chanvre 2007]. The moulds are oiled to make easy the mould removal. A cover is placed on the specimens during 5 days. Then the specimens were removed from the mould. The specimens are kept at 23 °C and 50% of relative humidity. The apparent density of this composite is 444 kg/m^3.

4 FOAMED BINDER

4.1 Formulation

The whole of the samples are realized with the lime based binder (Thermo® – BCB).

Fig. 25: Production process: Foaming process and Mineral foam sample.

This binder is mixed with water, with a Water/Binder ratio ranging between 0.4 and 0.67 (*Fig.* ***25***). In order to ensure a sufficient fluidity despite low water content, a plasticizer SP20 - K&Co is added (0.20% to 0.22% of the binder mass). A foam is obtained at pasty state thanks to the introduction of a surfactant (Hostapur OSB - Clariant, 0.1% to 0.3% of the binder mass). Sometimes a thickener such as CMC (walocel - DOW Chemical) is needed to ensure the foam stability.

4.2 Foaming process and Samples production

The used foaming process is the «direct foaming» method [Samson 2015]. This method leads to mineral foams with low water contents, even if the surfactant ratio is very small. The foam is generated through a unique step of mixing. All the components are mixed together to obtain a homogeneous mineral foam, thanks to a mixer equipped with a whisk (quick speed).

During the mixing step, air bubbles are trapped inside the concentrated suspension. Then the rheology of the mix is modified, so the foam can be done and stabilized [Buyn -] [Just 2009]. The duration of the mix step is modulated to generate a requested volume of the mineral foam. A calibration of this duration is necessary to generate foam with hardened density ranging between 500 kg/m^3 to 1100 kg/m^3. The produced foams are moulded at fresh state in cylindrical moulds (diameter 80 mm and height 200 mm). The mould removal is made after 24 hours. Then the samples are conserved at 20 °C and 50 %RH during 9 months. Then the samples are sawn to produce cylindrical samples with a slenderness close to 1. The samples are surfaced in order to ensure their flatness.

4.3 Samples without foaming agent

In order to study the contribution of the binder to the hygric and thermal properties, three samples (100 x 100 x 70 mm) are made without foaming process and using W/B ratio ranging from 0.4 to 0.6. The manufacturing and curing methods are the same as for hemp lime composite. These samples are named: binder. Samples densities are presented in Tab. 3.

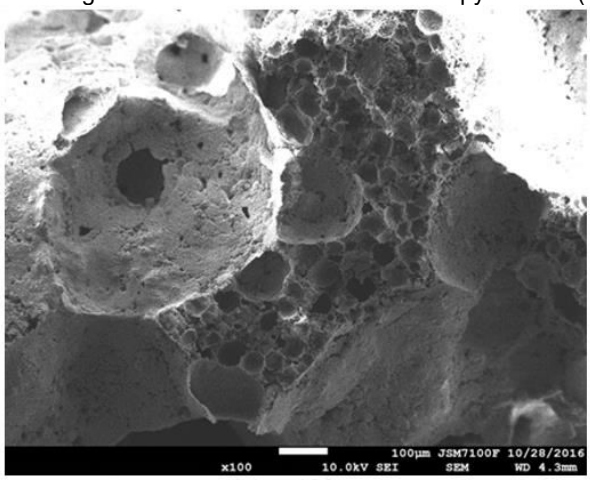
Tab. 32: Total water/binder ratio and apparent density

Materials	W/B	Apparent density kg/m^3

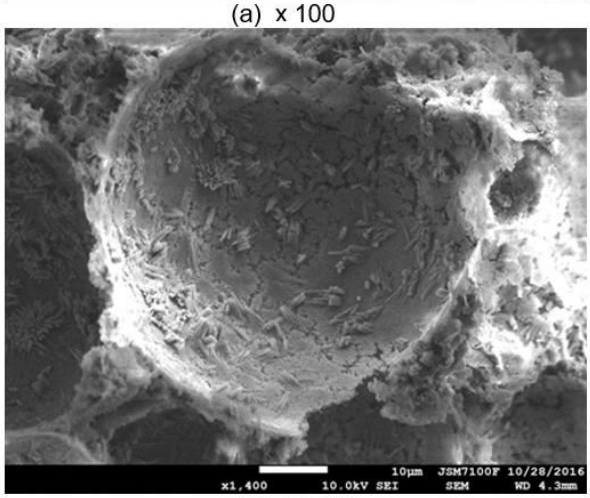
B 1	0.4	1277.34
B 2	0.5	1207.70
B 3	0.6	1126.94

4.4 Internal structure

The pore structure of foamed samples is visualized by scanning electron microscopy (



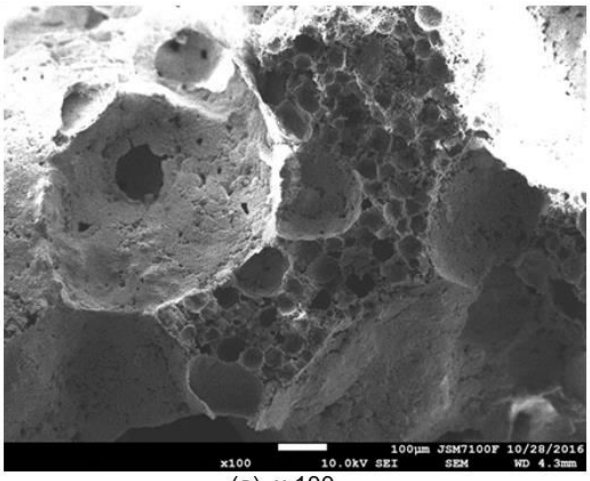
(a) x 100



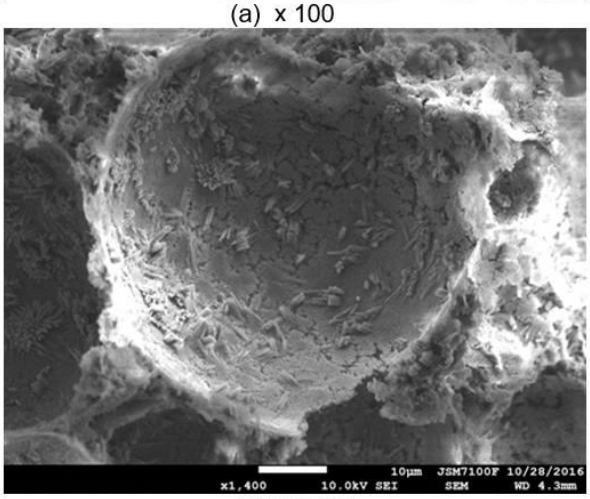
(c) x 1400

Fig. ***26***). The air bubbles present a diameter between 10 µm and 0.5 mm.

The connectivity between bubbles is low. Some surface cracking of the mineral matrix, due to shrinkage, is noticeable. The growth of the calcium carbonate on the bubble surface is shown in

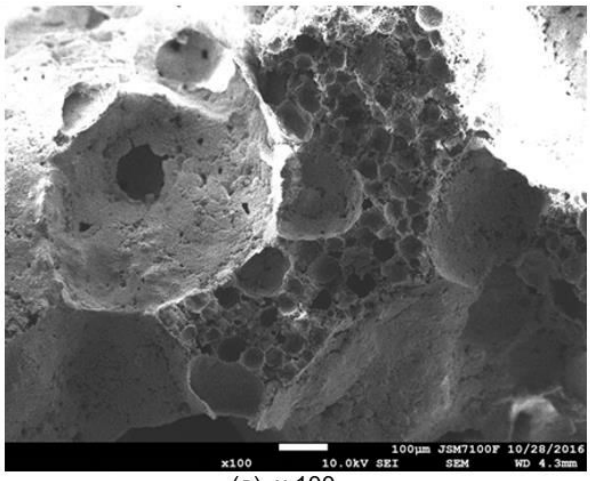


(a) x 100

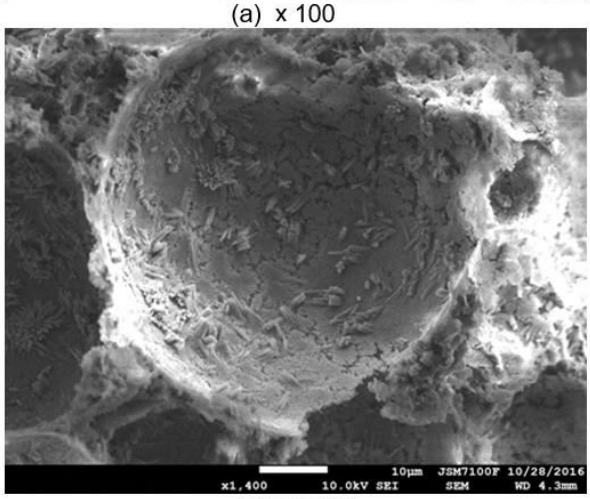


(c) x 1400

Fig. ***26***c. This observation indicates an advanced state of carbonation. The porosity inside the hardened matrix is very fine (< 1 µm) but is widely connected (



(a) x 100



(c) x 1400

Fig. ***26***d).The density of each foam sample is measured at fresh and hardened states. These values are used for the calculation of the porosity associated to voids due to air bubbles only (p_V) and induced in the mineral matrix (p_M) after binder hydration and drying.

In some cases, a kind of foam stability loss results in a partial collapse of the structure. This phenomenon leads more to a ripening effect (like a degassing) then to a coalescence.

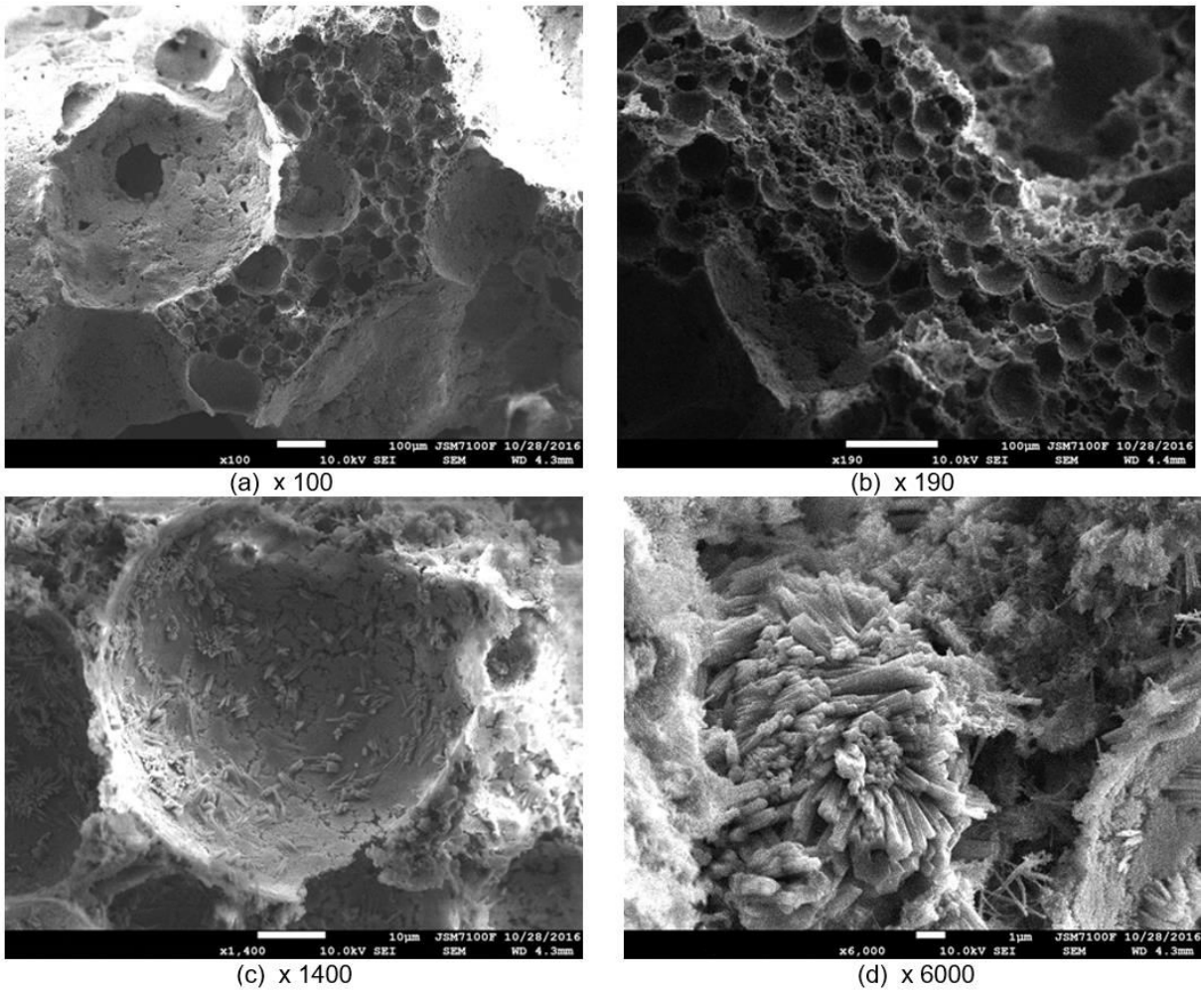


Fig. 26: View at SEM of inner structure of foams (a, b). Crystallisation of carbonate calcium on bubble surface (c). Inner structure of the mineral matrix (d).

5 RESULTS AND DISCUSSIONS

All the results are completed with results from [Collet 2013] and [Collet 2014]. They studied the hygric and thermal properties of other hemp lime composites formulated with an air slick lime or hydraulic lime (Tradical 70) from the same producer. The Hemp shiv / Binder ratios are in the same range: 0.5 to 0.65 and apparent density too: 430 to 460 kg/m^3. The Water/Binder ratios are quite higher: 0.8 to 1.6. Those three formulations are named: composite 2.

5.1 Thermal conductivity

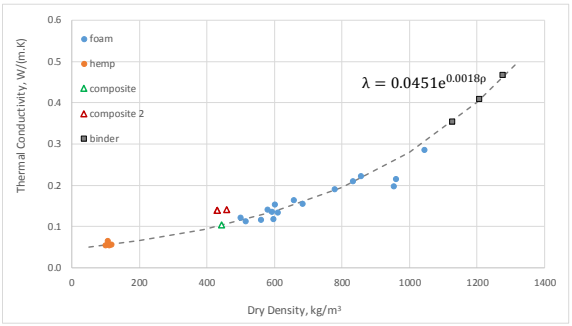


Fig. 27: Thermal conductivity vs density

The evolution of the thermal conductivity is an exponential function of the density (*Fig.* ***27***), whatever the type of materials, from binder to mineral foams, hemp lime composite and hemp shiv. The composite 2 data are not placed on the same tendency than the others values, certainly due to higher ratio of Water/Binder and to the use of other lime.

For the mineral foams and the binder samples, the effects of the mix proportioning changes are not visible. This tendency is relatively current for this kind of mineral matrix [Samson 2015] [Samson 2016]. For the same density, the thermal conductivity values of mineral foams and of hemp lime concrete, formulated with the same mineral matrix, are close.

5.2 Moisture Buffer Value

For Hemp shiv and mineral foams and also the hemp lime composite, the moisture buffer values (Fig. 9) range between 1.99 and 2.45 g/(m².%HR). According to the classification of the Nordtest project [Rode 2005], they are mostly excellent hygric regulators: MBV > 2 g/(m².%HR). For the hemp shiv, large MBV values are quoted. The large total porosity of shiv and large specific surface participate in such results. MBV largely increases with density. In the case of mineral foams, the lower densities lead to the higher MBV, showing the interest of large total porosity and of connexion between bubbles, increasing the air permeability. The spread of the mineral foams data seems due to the different pore structures of the foams. For the binder, MBV values range only between 1.22 to 1.57 g/(m².%RH), due to a large increase of total porosity and air permeability.

Curiously, the MBV values of hemp shiv and mineral foams are all higher than those of hemp lime composite and composite 2 (1.94 to 2.24 g/(m².%HR)).

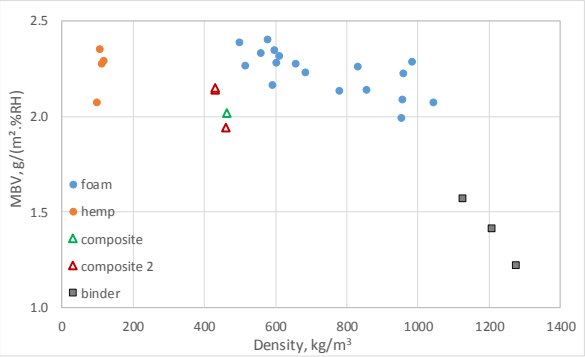


Fig. 28: Moisture Buffer Value vs Density

5.3 Discussion

It appears that there is no synergy between the contributions of the hemp shiv and the lime matrix to the hygric properties. To understand this phenomenon, it can be interesting to evaluate in each case the link between voids and matrix porosities and MBV.

First, the total porosity is studied (*Fig.* ***29***). Logically, according to the specific density of solid fractionof each material, Fig. 9 and Fig. 10 are quite symmetrical.

The relations between the MBV and the voids porosity and the matrix porosity are shown in *Fig.* ***30*** and *Fig.* ***31*** respectively.

For foams, composites and hemp shiv, a same tendency between the MBV values and the voids porosity p_V is highlighted. The higher is the voids porosity, the higher is the MBV. The linearity of the relation can be considered even though data are dispersed. For binders, MBV evolution is drastically different. At the time of manufacture, increase of water content in the paste induces higher matrix porosity (after drying) and lower voids porosity (less air volume trapped in the paste). Then voids porosity and matrix porosity are strongly coupled.

As a main conclusion, air bubbles enclosed in the material during sample production improve the MBV.

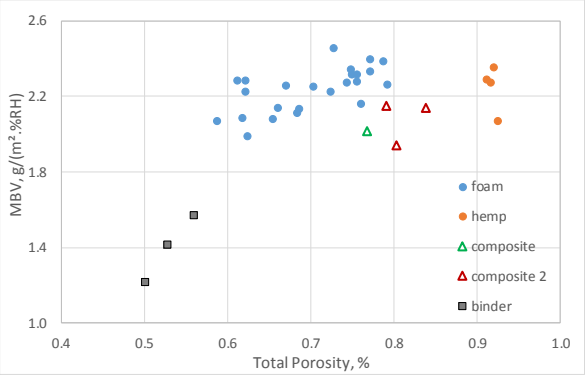


Fig. 29: MBV vs Total porosity

The tendency is opposite with the matrix porosity. All the data lead to the same linear decreasing tendency with the matrix porosity. The same remark regarding binders explain the position of data obtained with W/B = 0.4 and 0.5 excluded of the linear tendency.

The results indicate that the MBV seems to be regulated by the porosity of the materials. But it would be wrong to conclude that a better MBV value is obtained with a higher total porosity and then with a lower matrix porosity and a higher voids porosity.

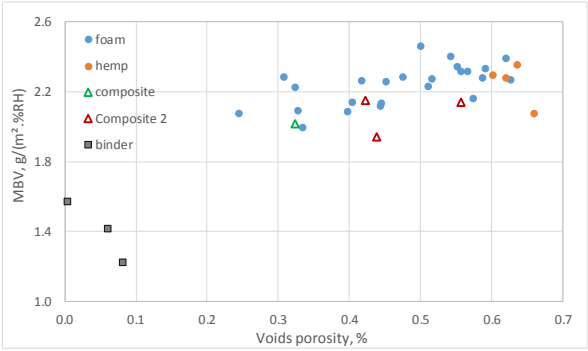


Fig. 30: MBV vs Voids porosity

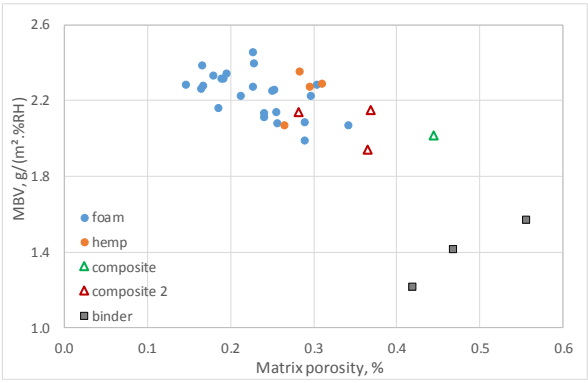


Fig. 31: MBV vs Matrix porosity

A linear model (Eq. 4) is proposed to separate the contribution of the matrix porosity (voids in the matrix) and the voids porosity (voids due to the hemp shiv arrangement, the bubbles into the foam or due to the mixing of hemp and lime):

$$\mathrm{MBV} = \mathrm{A}.\,p_M + \mathrm{B}.\,p_V \qquad (4)$$

In order to validate this relation, the experimental data must be lined up in a coordinate system MBV/p_M versus p_T/p_M (*Fig.* ***32***).

The data of each type of material lead to the fit of a straight line. The linear tendency obtained for mineral foams is evident. Data of composites lead to a linear tendency with a slope quite equivalent to those of foams. Because of the low number of data, the linear fit with hemp shiv data or binders data is more doubtful. However, the model parameters estimated from the linear regressions are presented Tab. 4. The values of A are high for mineral foam (4.15) and for hemp shiv (5.79), intermediate for composites and binders. Then matrix porosity is more efficient in the case of hemp shiv and mineral foams than for composites. More the contribution of voids porosity to MBV is higher in the case of mineral foams and composites than for hemp shiv and binder.

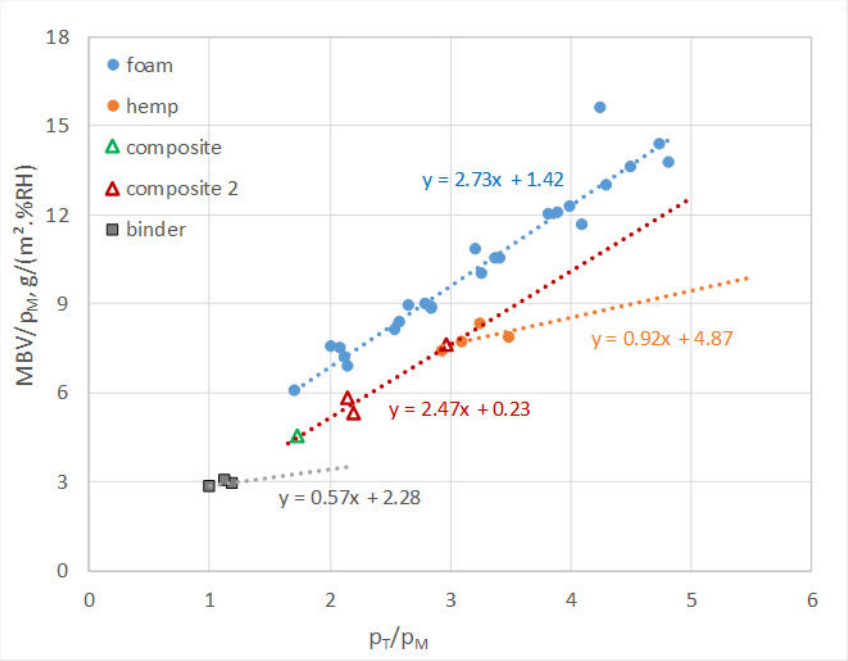


Fig. 32: Relation between the ratio $\frac{MBV}{p_M}$ and the ratio $\frac{p_T}{p_M}$

Tab. 33: Parameters of the MBV-porosity model

Materials	A	B
Hemp shiv	5.79	0.92
Mineral foam	4.15	2.73
Binder	2.85	0.57
Composite and composite 2	2.70	2.47

In all cases, the contribution of micro porosity, p_M, remains higher than those of macro porosity, p_V. Hemp shiv and mineral foam present large connection of the pore structure, together with large value of total porosity. Therefore, vapour transfer through the samples is easier. For binders, the total porosity is low and vapour transfer is slowed inducing lower contribution of matrix porosity to MBV. The contribution of bubble volume to the MBV in the case of mineral foams is quite in the same order than the contribution of air trapped in composites (for the same range of total porosity). Such observation cannot be generalized to the case of binders. The air bubbles present in the binder samples are separated and without direct connection as in the case of foams. Then, vapour permeability is penalised. Mineral foams appear as a good compromise with noticeable contribution of matrix and voids porosities.

In the case of composites, the deficiency of components synergy on MBV can be understand as a lower contribution of matrix porosity. Assuming that the composite is a mix of hemp shiv and binder, the MBV associated only to the matrix porosity (MBV_M) can be estimated using the calculated matrix porosity induced by hemp ($p_{M\text{-}HS}$) and by mineral matrix ($p_{M\text{-}B}$) with:

$$MBV_M = A_{HS}.p_{M\text{-}HS} + A_F.p_{M\text{-}B} \quad (5)$$

Where A_{HS} and A_F are the values of A parameter (Tab. 4) evaluated on hemp shiv and mineral foams. For the composite $MBV_M = 2.34$ as measured MBV = 2.02. Clearly, the contribution of the matrix porosity to the MBV is penalized by the mix. Coupling hemp shiv with the lime paste induces a reduction of vapor breathability. The mineral binder acts as a coating on the shiv reducing the connection of hemp shiv internal pores.

6 CONCLUSION

Hygrothermal performances evaluated on the different materials are full of interest to understand the contribution of each component of a hemp concrete. Thermal conductivity evolves with the density. At the same density, thermal conductivity of hemp concrete is quite equivalent to those of foamed binders. The change of binders in the hemp concrete induces noticeable changes on the thermal conductivity.

Moisture buffer values evaluated for each type of material lead to a classification of all the materials as good or excellent hygric regulator. Taking into account all the obtained data, MBV evolves with density. By extrapolation, an optimal values higher than 2.5 g/(m².%RH) is expected for a density close to 400 kg/m^3. However, such density is not accessible with mineral foams due to the increase of the foam collapse and to insufficient mechanical strength. It is noticeable that MBV of hemp concrete remains close to the lowest values measured for hemp shiv or foamed binder.

Thanks to the analyzing of the relation between MBV and the porosities, it appears that micro porosity (inside the matrix) is more influent than the macro porosity (trapped bubbles) on the MBV value. This influence shows the importance of specific surface on the moisture absorption. This phenomenon is more important in the case of hemp shiv than in the case of mineral foams. For Hemp concrete, the contribution of each type of porosity is quite balanced. The coating of the binder on the surfaces of the hemp shiv probably leads to the decrease of the available surface for moisture absorption. No synergetic effect of the two components is quoted. Obtain a mineral foam or a hemp shiv sample with density close to 400 kg/m^3 remains a promising challenge.

7 ACKNOWLEDGMENTS

This research receives some funding from European Union according to Horizon 2020 program (agreement n° 636835). All available information on the website: http://isobioproject.com/.

8 REFERENCES

[AFNOR 1996] AFNOR, Tests for geometrical properties of aggregates. Determination of particle size distribution. Test sieves, nominal size of apertures EN 933-2, 1996.

[Amziane 2013] Amziane, S.; Arnaud, L.; Bio-aggregate-based Building Materials: Applications to hemp Concrete, Wiley-ISTE, London, 2013

[Amziane 2017] Amziane, S.; Collet, F.; Bio-aggregates based building materials. State-of-the-Art Report of the RILEM Technical Committee 236-BBM. Springer. Rilem 2017.

[Arnaud 2012] Arnaud, L.; Gourlay, E.; Experimental study of parameters influencing mechanical properties of hemp concretes. Construction and Building Materials, 2012, Volume 28, pp 50-56.

[Buyn -] Buyn, K.; Song, H.; Sark, S.; Development of structural lightweight foamed concrete using polymer foam agent. Department of civil engineering, Seoul, n.d.

[Cérézo 2005] Cérézo, V.; Propriétés mécaniques, thermiques et acoustiques d'un matériau à base de particules végétales : approche expérimentale et modélisation théorique. Ph.D. thesis. Institut National des Sciences Appliquées de Lyon, 2005.

[Collet 2013] Collet, F.; Chamoin, J.; Prétot, S.; Lanos, C.; Comparison of the hygric behaviour of three hemp concretes. Energy and Buildings, 2013, 62, pp 294-303.

[Collet 2014] Collet, F.; Prétot, S.; Thermal conductivity of hemp concretes: variation with formulation, density and water content. Construction and Building Materials, 2014, 65, pp 612–619.

[Construire en Chanvre 2007] Association Construire en Chanvre; FFB ; Règles professionnelles d'exécution d'ouvrages en béton de chanvre. Ed. SEBTP, ISBN 9782915162448, 2007.

[De Bruijn 2013] De Bruijn, P.; Johansson, P.; Moisture fixation and thermal properties of lime-hemp concrete. Construction and Building Materials, 2013, 47, pp 1235-1242.

[Igathinathane 2009] Igathinathane, C. ; Pordesimo, L.O.; Columbus, E.P.; Batchelor, W.D. et al.; Sieveless particle size distribution analysis of particulate materials through computer vision. Computers and Electronics in Agriculture, 2009, 66, 147–158.

[Just 2009] Just, A.; Middendorf, B.; Microstructure of high-strength foam concrete. Material Characterisation, 2009, vol. 60, p. 741–8.

[Nguyen 2009] Nguyen, T.T.; Picandet, V.; Amziane, S.; Baley, C.; Influence of compactness and hemp hurd characteristics on the mechanical properties of lime and hemp concrete. European Journal of Environmental and Civil Engineering, November 2009, Volume 13, Issue 9, p. 1039-1050, ISSN 1964-8189.

[Nguyen 2010] Nguyen, T.T. ; Contribution à l'étude de la formulation et du procédé de fabrication d'éléments de construction en béton de chanvre (Contribution to the mix design and the manufacture process for products made of hemp concrete). Ph.D. thesis, Université Européenne de Bretagne, France, 2010 (in French).

[Nozahic 2012a] Nozahic, V. ; Vers une nouvelle démarche de conception des bétons de végétaux lignocellulosiques basée sur la compréhension et l'amélioration de l'interface liant/ végétal application à des granulats de chènevotte et tige de tournesol associés à un liant ponce/ chaux. Ph.D. Thesis, Université Blaise Pascal, 2012

[Nozahic 2012b] Nozahic, V.; Amziane, S.; Torrent, G.; Saïdi, K. et al.; Design of green concrete made of plant-derived aggregates and a pumice–lime binder. Cement & Concrete Composites, February 2012, Volume 34, Issue 2, p. 231-241, ISSN 0958-9465.

[Picandet 2012] Picandet, V.; Tronet, P.; Baley, C.; Caractérisation granulométrique des chènevottes. XXXe Rencontres AUGC-IBPSA Chambéry, France, 2012.

[Rode 2005] Rode, C.; Moisture buffering of Building Materials, Report BYG•DTU R-126, ISSN 1601 – 2917, ISBN 87-7877-195, 2005.

[Samson 2015] Samson, G. ; Synthèse et Propriétés des mousses minérales, Ph.D. thesis, INSA de Rennes, France, 2015.

[Samson 2016] Samson, G.; Phelipot-Mardelé, A.; Lanos, C.; Thermal and mechanical properties of gypsum-cement foam concrete: effects of surfactant. EJECE, 2016, DOI: 10.1080/19648189.2016.1177601.

[Tran 2010] Tran Le, A.D. ; Etude des transferts hygrothermiques dans le béton de chanvre et leur application au bâtiment. Ph.D. thesis, Université de Reims Champagne-Ardenne, France, Novembre 2010.