3rd International Conference on Bio-Based Building Materials

June 26th - 28th 2019
Belfast, UK

TOWARDS A BETTER UNDERSTANDING AND KNOWLEDGE OF BIOBASED MATERIALS THROUGH A NEW ACOUSTIC DATABASE

P. Glé[1]*, T. Blinet[2], C. Guigou-Carter[3], T. Falwisanner[1], E. Kadri[2], F. Bou-Cherifi[4]

[1] Cerema, Ifsttar, UMRAE, Strasbourg, 67200, France

[2] CSTB, 84, avenue Jean Jaurès, Champs-sur-Marne, 77420, France

[3] CSTB, 24 Rue Joseph Fourier, Saint Martin d'Hères, 38400, France

[4] DGALN/DHUP/QC2, 1 place Carpeaux, La Défense 6, La Défense, 92055, France

*Corresponding author; e-mail: philippe.gle@cerema.fr

Abstract

In this work, the acoustical performances of building elements including natural sustainable fibrous and granular materials have been evaluated to create a new database. These characterisations have been carried out at two scales. On the one hand, the physical parameters of the considered biobased materials have been characterised in Cerema laboratory at the material scale; the sound absorption and transmission loss were mainly obtained in normal incidence from Kundt tube measurements, following the three microphones method. On the other hand, measurements have been performed in CSTB facilities in diffuse field conditions to characterise the acoustical performances (sound absorption, airborne sound insulation) of larger scale elements.

The parameters evaluated at the material scale have then been injected into a prediction software in order to predict the acoustic performance of the building elements. In the present case, the CSTB software AcouSYS based on a transfer matrix approach and integrating a spatial filtering method to take into account the finite size of building systems and a coupling with a SEA approach to take into account structural paths, has been mainly used.

Several types of biobased materials have been considered, including wood, cotton and hemp wools, but also hemp concretes and cellulose wadding. The acoustic performance of building elements including biobased fibrous materials are compared to similar ones including more standardly used material such as mineral wool.

Keywords:

Acoustical performances; Biobased materials; Airborne sound insulation, Sound absorption

1 INTRODUCTION

To date, the deployment of solutions based on biobased materials is affected by a lack of knowledge regarding their acoustical performance (at the material and system scales), which complicates the task of project management during the design phase of a building. The project manager does not have the necessary elements to properly integrate these biobased solutions into the building. Moreover, the actors are generally small sized, poorly structured trade unions and do not always have a great knowledge of technical-regulatory issues and/or the necessary means to characterise and certify their products.

Biobased materials are characterised by a regulatory definition, as specified in the Decree of 19 December 2012 on the content and conditions for the award of the "biobased building" label [Legifrance 2012]. These are materials derived from living organisms of animal (e. g. sheep's wool) or vegetal origin (e. g. wood, straw). An update study carried out in 2013 by the General Commission for Sustainable Development (CGDD) defines these biobased materials as "all biomass materials as opposed to traditional petroleum-based materials. They are either present in living organisms (plants or animals) or synthesized by them, or they are derived from products and by-products of cereals, oilseeds and protein crops, fibrous plants or wood."

A study funded by the French Ministry of Ecology has been carried out last year involving Cerema and CSTB laboratories, to overcome this limited knowledge and to make the sector progress in the field of acoustics. This is in line with the missions of this Ministry which supports biobased materials for several years. A first step has been carried out in this context to provide a state of the art on the acoustic data available for biobased materials [Blinet 2017, Glé 2018].

More recently, in a second step, experimental characterisations as well as simulations have been performed, to evaluate and understand the acoustical behaviour of a large selection of bio-based materials, including vegetal wools, loose vegetal fibres or particles, hemp concretes and straws. This research was conducted at two levels, linking the material scale properties to the system scale performances [Blinet 2018]. Indeed, the material scale properties are necessary input data to simulations at the system scale.

We focus on a selection of the results of this study in the present paper organized around two sections: First section deals with the material scale characterisations and modellings, while measurements at the system scale and associated simulations are presented in the second section.

2 MATERIALS CHARACTERISATION

Material-scale characterisation are carried out independently of the system implemented in buildings (suspended ceiling, fixing to metallic rails or studs for partitions, possible reinforcement, etc.). The material scale is thus associated with limited dimensions (about 10 cm), which is reduced compared to the scale of a building system such as a wall. This approach is interesting in the way it makes it possible to characterise very finely the dissipation phenomena that may exist in these porous materials (visco-inertial, thermal and mechanical dissipations) and that are often mixed in larger scale characterisations with other effects (multilayer coupling, mechanical behaviour of the wall, problematic direct or indirect transmissions).

2.1 Acoustical properties characterisation

Approach

Sound absorption coefficient α and transmission loss TL allow assessing the performance of materials for acoustic correction or sound insulation purposes, and have been characterised for the biobased materials under study. The intrinsic quantities of the material (dynamic density and bulk modulus) were characterised at the same time to capture the acoustical dissipation [Allard 2009].

A Kundt tube AcoustiTube (AFD1000/AFD1200) was used. The choice of an inside diameter of 10 cm was made in order to minimize the edge effect (imperfect arrangement due to large particle size in relation to the tube) on aggregates and hemp concrete. Due to its dimensions, this tube therefore allows characterisations at normal incidence in the range [50; 2000 Hz].

The implemented measurement method is based on the use of three microphones (two upstream in the sample, and a third downstream), and was initially described in [Iwase 1998]. This method is an extension of the traditional Kundt tube characterisation method defined in standard NF EN ISO 10534-2:2003.

Four families of biobased materials are studied here: loose vegetal fibres, loose vegetal particles, vegetal wools and hemp concretes. For each family, measurements have been performed on 3 to 5 samples to ensure the representativeness of the characterisation (averaged data is presented). Moreover, for loose materials, the effect of density has also been investigated to explore the range of possible properties (min and max density are presented in this paper). A global overview of the materials and their characteristic is provided in Tab. 1.

Loose fibrous materials

Results presented in Fig. 1 show very different sound absorptions and attenuations for loose fibres, which is explained by the wide range of density, and associated resistivity. Hemp fibres are the least resistive, due to the long length of the fibres and the elasticity of the material under compaction. On the contrary, cellulose wadding and recycled cotton are very easily compacted due to their small fibre size, which allows high levels of absorption and transmission loss. Finally, there is a very significant effect of the density (in this case material compaction) on the performance of these materials, which could be seen at the system scale.

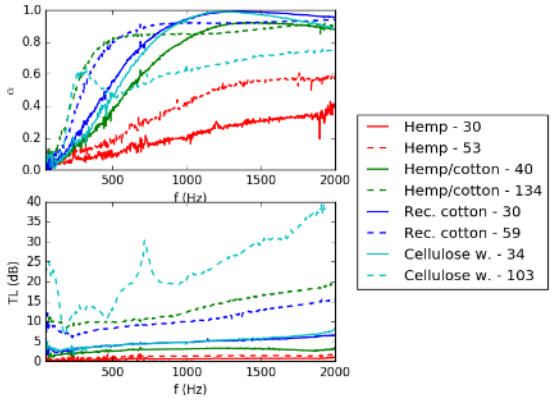

Fig. 1: Acoustical properties of loose fibres

Loose particles

The biobased aggregates considered here are husks or hulls, and correspond to the envelop of seeds growing within corresponding plants. These aggregates are used in various forms (bulk, concrete, plasters, panels) mainly for thermal insulation purposes in buildings.

The performance of these aggregates, presented in Fig. 2., is quite nuanced in terms of sound absorption and attenuation. This is related to the different granulometries encountered and the associated applicable density ranges. Thus, the smaller the aggregates are, the easier it is to arrange the material and to increase density, resistivity and therefore sound absorption and transmission loss. For this reason, buckwheat hull offers the best performance.

In addition, there is a systematic but moderate effect of density for the same material, resulting in a shift of the absorption peak to low frequencies and a gain in transmission loss.

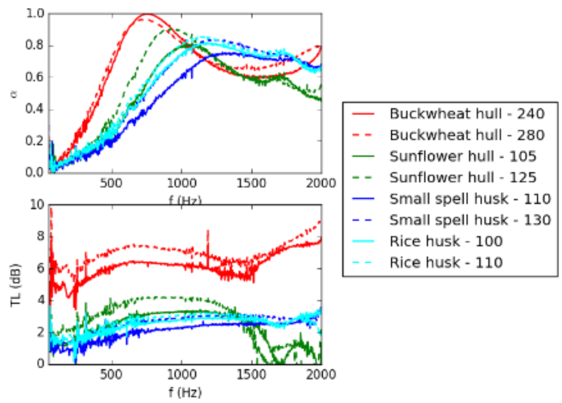

Fig. 2: Acoustical properties of loose husks and hulls

Vegetal wools

The acoustical properties of vegetal wools are presented in Fig. 3. The wools are all good sound absorbers due to their intermediate resistivity range (4,000 to 15,000 Nm^{-4}s). Wood wools are generally of higher density, which gives them a higher resistivity and a stronger transmission loss.

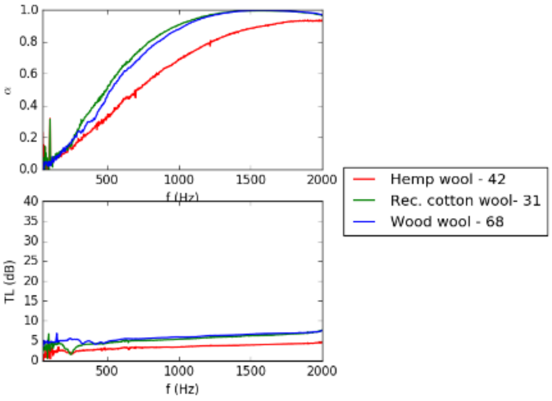

Fig. 3: Acoustical properties of vegetal wools

Hemp concretes

Two hemp concretes were also produced in this study (formulation type "Wall"). Coatings were manufactured at the same time but were not characterised at the material scale, as they were too resistive to be characterised as porous material (in this case, the mechanical characteristics are sufficient to take them into account in the system scale modelling). Results are presented in Fig. 4.

First of all, we can see in Tab. 1 that the densities of these concretes are very different and do not correspond to the implementation applied at the system scale, as the projection generally makes it possible to reach lower densities than in shuttering (Light concrete results here from shuttering process while heavy one from projection). This is explained by the fact that the material-scale samples were moulded in parallel with the manufacture of the larger walls, and that a "similar" implementation was not possible due to the small size of the moulds. The direct use of these parameters for the system scale is therefore not possible. The characterised performances are in line with the densities of the samples, and underline two almost extreme behaviours encountered in hemp concrete: Light concrete is porous with good absorption and limited attenuation, while the denser concrete presents a very closed porosity, which gives it a fairly reflective and sound insulating behaviour.

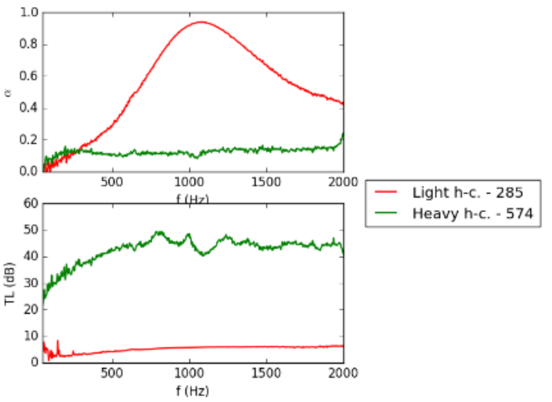

Fig. 4: Acoustical properties of hemp concretes

2.2 Material scale modelling and acoustical parameters

Approach

The fundamental acoustic parameters of porosity ϕ, resistivity σ, tortuosity α_∞, viscous and thermal lengths Λ and Λ', and thermal permeability k_0', are more relevant when discussing differences between materials from a microstructural point of view, and were also evaluated during this study.

To determine the open porosity of the materials, an air porosimeter based on the method described in [Leclaire 2003] was used. The resistivity is evaluated in accordance with ISO 9053:2018. For the other parameters, it is very complicated to carry out direct experimental characterisations, but very robust alternatives have been proposed in the literature. We have thus used the indirect characterisation method developed by Olny and Panneton (see [Panneton 2006] and [Olny 2008]). This method consists in exploiting the intrinsic performances of materials in their complex form to analytically trace back to the desired parameters (α_∞, Λ, Λ', and k_0') based on the semi-phenomenological models described in [Johnson 1987] and [Lafarge 1997], forming the approach noted here JCAL for Johnson-Champoux-Allard-Lafarge. For this, a prior knowledge of the other parameters of these models (ϕ and σ) is required. In case the actual porosity cannot be directly known (case of some vegetal particles or concretes), an alternative is to calculate the ratio α_∞/ϕ in this procedure and estimate the porosity based on the real part of the bulk modulus only, with a simplified model such as Zwikker and Kosten one [Zwikker 1949]. In this case, the approach used is noted as JZK for Johnson-Zwikker-Kosten [Glé 2013].

Results

The synthesis of the acoustical parameters characterised following this approach is presented in Tab. 1. For the various kinds of materials (loose fibres and particles, wools and concretes), the modelling captures quite well the experimental behaviour. However, few limitations must be discussed. First, as for instance in Fig. 5, it can be seen that the modelling does not account for the possible mechanical resonance (in this case occurring around 200 Hz). The approach is based on a rigid frame hypothesis, so that mechanical dissipation is introduced at system scale thanks to complementary measurements (elasticity modulus, damping – See Sec. 2.3).

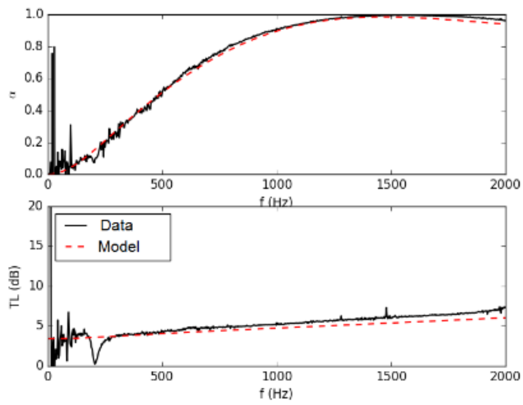

Fig. 5: Modelling of the recycled cotton wool

Moreover, another behaviour has been highlighted during our measurement, in the case of husk and hulls with an additional resonance. Fig. 6 gives an example of this behaviour, which is not clearly understood at this time, but might be linked to a mechanical resonance of the skeleton or to an inner resonance linked to open cavities existing in these aggregates.

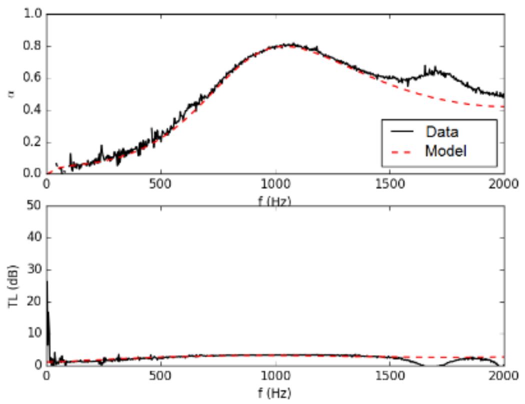

Fig. 6: Modelling of the sunflower hull

2.3 Mechanical parameters characterisations

Dynamic stiffness measurements have been carried out in accordance with standard NF EN 29052-1:1992 in the case of relatively "flexible" materials, such as insulating materials (wools, loose fibres). The longitudinal dynamic elastic modulus is determined according to standard NF EN 14146:2004 in the case of more "solid" materials such as hemp concrete and coatings. The Young's modulus and loss factor of some of the biobased materials have been evaluated with these methods and used as input parameters for the system-scale simulation. Results are indicated in Table 1 (Young's modulus is noted E, loss factor η and Poisson's ratio ν).

Young's modulus of vegetal wools range between 0.035 and 0.09 MPa with loss factor ranging between 5 and 8%, which is in line with conventional fibrous materials. For hemp concretes, only denser concrete has been tested, since the lighter samples were too fragile to be characterised. Young's modulus reaches 642 MPa. The coatings used with these concretes presents Young's modulus of about 4000 MPa. Concerning loose materials, results were very dispersed with a strong dependence to the material configuration. A dedicated setup has to be developed to achieve better and meaningful characterisation in this case.

3 EVALUATION OF SYSTEMS PERFORMANCES

The mechanical and acoustical parameters determined and presented in Sec. 2 are used as input data in a simulation tool allowing to obtain acoustic performance at system scale. In the present section measured and predicted acoustic performance of building systems including biobased materials are presented and compared.

3.1 Experimental investigations

Measurement methods

In this section, the results of laboratory measurements on systems integrating biobased materials are presented. Standard building systems have been selected for these laboratory tests, integrating measurement of airborne sound reduction for:

- Vertical walls (Partition on metal frame, Hemp concrete wall);

- Horizontal walls (Ceiling below undeveloped attic).

These measurements have been performed in CSTB facilities, following standard NF EN ISO 10140-2:2013 and NF EN ISO 10140-5:2013, in a test unit composed of a pair of decoupled transmission and reception rooms. Results are presented between 50 and 5000 Hz. The dimensions are 4.2 by 2.5 m² for the vertical tested systems and 4.2 x 3.6 m² for the horizontal ones.

Simulations

Acoustic performance is predicted using a transfer matrix method (TMM) [Allard 2009, Munjal 1993] implemented in AcouSYS software developed and commercialized by CSTB. The different layers of constant thickness constituting the structure can be solid, fluid, porous (according to the generalized Biot-Allard theory [Biot 1956] or viscoelastic. This tool can be used to predict sound reduction index, impact sound level, sound absorption, rainfall noise, propagation constants and turbulent boundary layer noise.

A method of spatial windowing is used to take into account the finite dimensions of the studied systems [Villot 2001], when subjected to air-borne excitation.

Structural connexions due to the presence of framing elements are taken into account by SEA (Statistical Energy Analysis) an energetic method [Guigou-Carter 2006] at medium and high frequencies for calculation time reasons. At low frequencies, a wave approach is used which considers the framing elements as springs modelled by normal linear forces.

A FEM approach can also be used to improve prediction, especially of low frequencies with the presence of modal behaviours [Coguenanff 2015].

Results for single frame partition wall

The partition tested consists of a standard M48/R48 metal framework with a single layer of 12.5 mm thick plasterboard on each side. The cavity is filled with a 45 mm thick hemp wool. For the simulation approach, the filler material is considered to have no contact with plasterboards. This boundary condition implies that t the mechanical characteristics of the insulating materials have a negligible influence. This is valid since the strongest coupling between the partition sides is associated to the metal framework. (This has been checked on the basis of the mechanical parameters characterised and discussed in Section 2.3).

Fig. 7 compares the measurement and the simulation of the sound reduction index per one-third octave band for the partition with hemp wool. The observed behaviour is typical of mass/spring/mass systems, with a breathing resonance frequency at 150 Hz. The critical frequency of the plasterboard can be observed in the high frequency range around 3000 Hz. The performance measured, $R_w(C;C_{tr})$=40(-5;-11), is of the same order than conventional materials (glass wool) and is in close agreement with the simulation.

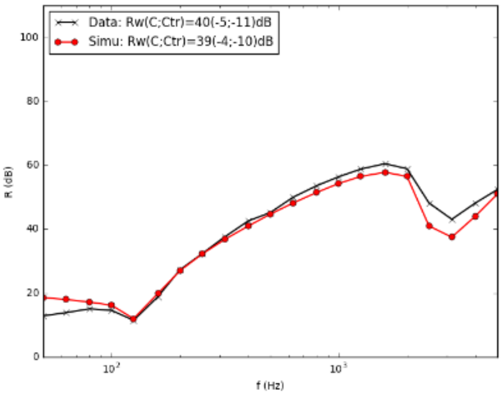

Fig. 7: Comparison between measurement and simulation of the sound reduction index R of a 72-48 partition wall with 45mm hemp wool filling

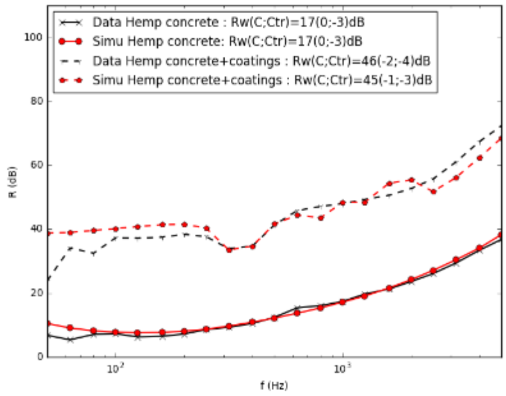

Fig. 8: Comparison between measurement and simulation of the sound reduction index R of a hemp concrete façade wall without and with coatings

Results for hemp concrete walls

Two hemp concrete wall have been tested in this study, without and with concrete:

- a 320 mm thick wall (facade wall) has been built by shuttering with light hemp concrete (~300 kg.m^{-3}), around a wood frame with 115x35 mm² elements and a 600 mm spacing. Lime coatings have been applied on both sides after drying, with 13 and 20 mm thickness respectively;

- a 270 mm (separation wall) has been built by projection with heavier hemp concrete (~500 kg.m^{-3}) around a wood frame with 110x60 elements and a 600 mm spacing. Finishing on both sides has also been applied with a BA13 plasterboard glued by dabs (8/m²) for one side, and a 15 to 20 mm thick lime coating for the other side.

For the facade wall, Fig. 8 shows the sound reduction index measured and simulated in both cases (without and with coatings). It is clear here that the coatings bring an interesting contribution (more than 10 dB) to the sound reduction of the raw wall, which is quite low, probably due to the low density and resistivity of the material and the manufacture process (vertical discontinuities). However, the acoustic performance measured with coatings (R_w+C_{tr} of 42 dB) should allowed fulfilling the minimum French façade sound insulation (30 dB in terms of $D_{nT,w}$+C_{tr}). Besides, a resonant behaviour is visible around 350 Hz for the wall with coatings, and might be linked to a critical frequency of the system coating/wall/coating. The mass/spring/mass type resonance (coatings acting as masses around the hemp concrete being the spring) might be located in this case around 2500 Hz, with a change of the slope. The agreement with the TMM approach is satisfactory in both cases, under the condition that the parameters are adapted. As said previously, the data characterised on moulded hemp concrete samples are not systematically representative of the material at the system-scale.

For the separation wall, results are presented Fig. 9. The performance of the raw wall is greater than for facade wall (greater density, homogeneity of the material obtained with projection technique). Again, an interesting gain is achieved with the finishing on both sides. It is to be noted that the acoustical performance of this wall with finishing on both sides is of same order than a 300 mm thick hollow brick wall with coatings on both sides. For the modelling, the material-scale parameters have also been adapted here to reproduce the experimental behaviour. However, differences are still visible above 800 Hz, which is not explained at this time (wood frame effect, coupling conditions between layers, orthotropy of the raw wall, …).

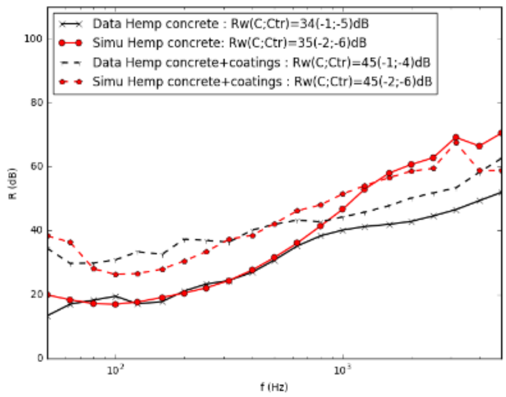

Fig. 9: Comparison between measurement and simulation of the sound reduction index R of a hemp concrete separation wall without and with coatings

Results for ceiling below undeveloped attic

The last configuration presented here at system-scale concerns the case of a ceiling below undeveloped attic. The system consists of 160 mm x 60 mm beams spaced every 500 mm, with 350 mm thick biobased insulation placed between the beams. The ceiling is composed of a single layer of 12.5 mm thick plasterboards mounted on metallic furring channels and short hangers. Results are presented in Fig. 10 with two loose filling materials: hemp/cotton fibres and cellulose wadding.

In the modelling approach, a contact is considered between loose materials and plasterboards layer (since the insulation material rests on the plasterboards layer). Thus, the mechanical parameters of the materials may have an impact on acoustic performance as the skeleton of the porous material is excited. This situation corresponds to the standard assumption for this type of system. However, since mechanical parameters have not been measured for this kind of materials (difficulty of characterisation due to a low cohesion, see Sec. 2.3), values typical of similar materials have been used (E=0,035 MPa for hemp cotton wool and 0,05 MPa for cellulose wadding, with a loss factor of 7%).

The experimental results show a greater sound reduction for cellulose wadding filling, which is related to the greater resistivity of this material. It also appears that the predicted sound reduction index is very close to that measured. The difference observed in the high frequencies between prediction and measurement for hemp/cotton fibres insulation has no influence on the overall performance of the system. This difference is certainly linked to the mechanical parameters estimate.

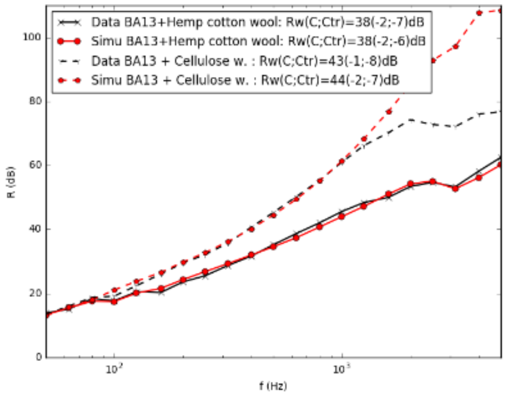

Fig. 10: Comparison between measurement and simulation of the sound reduction index R of a ceiling with loose fibres (hemp/ cotton fibres and cellulose wadding) insulation

3.2 Results extension

On the basis of the previous data and modelling approach validation, theoretical extensions of the acoustical performances of systems integrating biobased materials are proposed here.

Single frame partition wall

In Fig. 11, results for single frame partition walls are extended to two other vegetal wools: Recycled cotton and wood wools having the same thickness of 45 mm. It is thus shown that the effect of the filling for this range of materials is very limited (± 1 dB variations). Indeed, the effect of the metal framework connecting the plasterboards is essential in this case. However, differences can be observed in the high frequencies around the critical frequency of plasterboard around 3000 Hz.

These small differences can be attributed to the acoustical parameters on the basis of a previous study [Foret 2010], showing that the tortuosity and resistivity had an influence above the third octave 800 Hz and the characteristic lengths above the critical frequency; the porosity having an impact on all the frequency band studied.

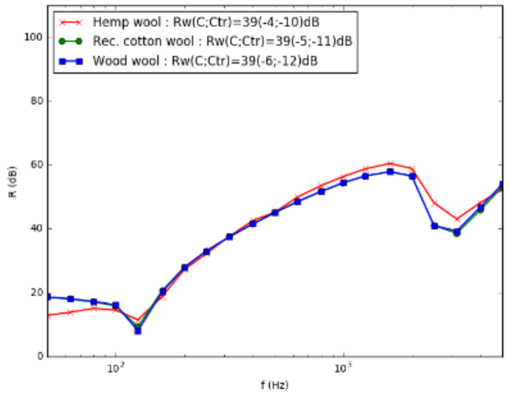

Fig. 11: Simulation of the sound reduction index R of a 72-48 partition wall with various wools filling

Hemp concrete wall

Extensions of the results for hemp concrete are not presented in this paper but can be found in [Blinet 2018]. For thicknesses of hemp concretes ranging between 300 and 400 mm, it is shown that the sound reduction index increases gradually but in a limited way (±1 dB) because of the sound reduction index behaviour in the mid frequency range (around the one-third octave bands of 315 and 400 Hz). As a result, it seems relevant to optimize the coating layers in this case to achieve high sound reduction levels.

Ceiling below undeveloped attic

For ceiling below undeveloped attic, results have been extended to eight loose materials, involving loose fibres and loose aggregates. Since the mechanical parameters of the loose aggregates were not characterised, they have been considered representative of this kind of material (loss factor of 7% for all materials, E = 0.25 MPa for granular materials and E in the range 0,035-0,06 MPa for fibrous materials) [Blinet 2018]. In this case, a greater dispersion of the results is observed and can be directly related to the differences in terms of resistivity, density and elasticity between the materials. The systems associated with high performance should most probably be implemented and tested in the laboratory in order to validate the observed behaviour. Furthermore, the ceiling system might have to be reinforced (number of plasterboards layers, furring channels, etc..) in order to accommodate the heavy biobased materials.

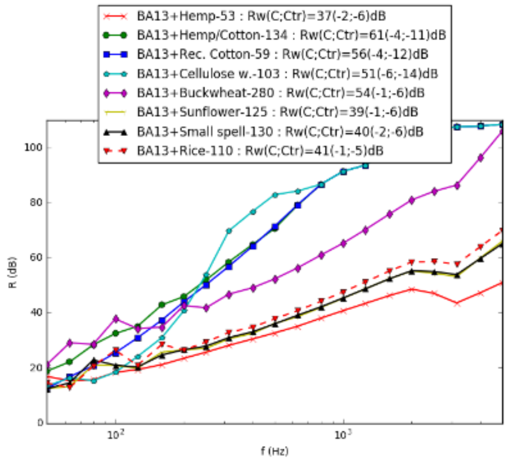

Fig. 12: Simulation of the sound reduction index R of a ceiling with loose fibres or aggregates insulation

4 CONCLUSIONS

A large experimental campaign on the acoustical properties of biobased materials has been carried out to get a better understanding of these materials. Measurements and modellings have been realised at material and system scales on loose vegetal fibres and particles, and hemp concretes in various configurations (single frame partition wall, ceiling, …).

In the different cases, a good agreement is found between the experimental data and the simulations, which validates the approach developed. On this basis, extensions of the results are proposed to other configurations. An interesting result is that it can be considered that building systems integrating biobased materials present same level of acoustical performance that another system with more conventional material, such as mineral wool.

This work highlights also the need for further studies in this field, to investigate more deeply some of the results at material and the system scales, one priority being the determination of the mechanical parameters of loose materials.

For a complete overview of this study, we invite the readers to refer to the public complete study report [Blinet 2018].

5 ACKNOWLEDGMENTS

The authors would like to thank the French Direction of Housing, Town Planning and Landscapes (DHUP) for funding this work.

6 REFERENCES

[Allard 2009] J.F. Allard, N. Attala, Propagation of Sound in Porous Media: Modelling Sound Absorbing Materials, John Wiley & Sons (2009).

[Biot 1956] M.A. Biot, Theory of elastic waves in a fluid saturated porous solid. I. Low frequency range, II. Higher frequency range, J. Acoust. Soc. Am., 28, 168-91 (1956).

[Blinet 2017] T. Blinet, P. Glé, C. Guigou-Carter, Propriétés acoustiques des matériaux biosourcés, Rapport phase 1 CSTB-Cerema-DHUP (2017).

[Blinet 2018] T. Blinet, P. Glé, T. Falwisanner, C. Guigou-Carter, E. Kadri, Propriétés acoustiques des matériaux biosourcés, Rapport final CSTB-Cerema-DHUP (2018).

[Coguenanff 2015] C. Coguenanff, Robust design of lightweight wood based systems in linear vibroacoustics, Thèse CSTB - Université de Paris-Est (2015).

[Foret 2010] R. Foret, C. Guigou-Carter, J.-B. Chéné, Porous material parameters influencing the acoustic performances of buildings construction systems, Internoise 2010, Portugal (2010).

[Glé 2013] P. Glé, Acoustique des Matériaux du Bâtiment à base de Fibres et Particules Végétales. PhD Thesis ENTPE - Université de Lyon (2013).

[Glé 2018] P. Glé, T. Blinet, C. Guigou-Carter, Acoustic performance prediction for building elements including biobased fibrous materials, Euronoise 2018, Greece (2018).

[Guigou-Carter 2006] C. Guigou-Carter, M. Villot, Analytical and experimental study of single frame double wall, Euronoise 2006, Finland (2006).

[Iwase 1998] T. Iwase, Y. Izumi, R. Kawabata. A new measuring method for sound propagation constant. Internoise 98, New Zealand (1998).

[Johnson 1987] D-L. Johnson, J. Koplik, R. Dashen. Theory of dynamic permeability and tortuosity in fluid-saturated porous media. Fl Mech 176, 379–402 (1987).

[Lafarge 1997] D. Lafarge, P. Lemarinier, J-F. Allard, V. Tarnow. Dynamic compressibility of air in porous structures at audible frequencies. J Acoust Soc Am 102 (4), 1995–2006 (1997).

[Leclaire 2003] P. Leclaire, O. Umnova, K-V. Horoshenkov et L. Maillet, “Porosity measurement by comparison of air volumes”, Review of scientific instruments, vol. 74 (3), p. 1366–1370, 2003.

[Legifrance 2012] https://www.legifrance.gouv.fr /eli/arrete/2012/12/19/ ETLL1239803A/jo

[Munjal 1993] M.L. Munjal, Response of a multi-layered infinite plate to an oblique plane wave by means of transfer matrices, J Sound Vib 162, 333-343 (1993).

[Olny 2008] X. Olny, R. Panneton. Acoustical determination of the parameters governing thermal dissipation in porous media. J Acoust Soc Am 123 (2), 814–824 (2008).

[Panneton 2006] R. Panneton, X. Olny. Acoustical determination of the parameters governing viscous dissipation in porous media. J Acoust Soc Am 119 (4), 2027–2040 (2006).

[Villot 2001] M. Villot, C. Guigou-Carter, L. Gagliardini. Predicting the acoustical radiation of finite size multi-layered structures by applying spatial windowing on infinite structures, J Sound Vib 245 (3), 433-455 (2001).

[Zwikker 1949] C. Zwikker, C-W. Kosten. Sound Absorbing Materials. Elsevier, New-York (1949).

Tab. 1: Characteristics and acoustical/mechanical parameters of the biobased materials (indicates that parameter has been estimated when no data were available, or adapted)*

Reference	**Thick.**	**Density**	**Model**	ϕ	σ	α_∞	Λ	Λ'	k_0'	E	η	ν
	mm	*kg.m*$^{-3}$		-	*Nm*$^{-4}$*s*	-	*µm*	*µm*	*10*$^{-8}$*m*^{2}	*MPa*	*%*	-
Hemp	60	28	JCAL	0,982	219	1,04	693	3430	8,66	0,04*	7*	0
Hemp	60	53	JCAL	0,965	600	1,11	315	2110	4,62	0,04*	7*	0
Hemp/Cotton	60	40	JCAL	0,974	2377	1,00	101	529	1,61	0,06*	5*	0
Hemp/Cotton	60	134	JCAL	0,911	27262	1,00	21	103	0,42	0,06*	5*	0
Recycled cotton	60	59	JCAL	0,98	5416	1,00	94	139	0,59	0,06*	5*	0
Recycled cotton	60	59	JCAL	0,96	23621	1,00	41	77	0,32	0,035*	7*	0
Cellulose wadding	50	34	JCAL	0,977	6288	1,00	57	101	0,73	0,035*	7*	0
Cellulose wadding	50	103	JCAL	0,932	116491	2,33	19	146	1,58	0,05*	5*	0
Buckwheat hull	50	240	JCAL	0,840	11272	3,38	173	4,2	1,53	0,25*	7*	0
Buckwheat hull	50	280	JCAL	0,813	15816	3,14	119	310	1,30	0,25*	7*	0
Sunflower hull	50	105	JCAL	0,930	2318	2,63	282	3400	7,89	0,25*	7*	0
Sunflower hull	50	125	JCAL	0,917	3793	2,99	221	2580	7,20	0,25*	7*	0
Small spelt husk	50	110	JCAL	0,927	1615	1,64	250	1830	3,47	0,25*	7*	0
Small spelt husk	50	130	JCAL	0,913	2566	1,78	202	1450	2,99	0,25*	7*	0
Rice husk	50	100	JCAL	0,933	2691	1,89	220	700	3,30	0,25*	7*	0
Rice husk	50	110	JCAL	0,927	3070	1,93	193	590	3,06	0,25*	7*	0
Hemp wool	45	42	JCAL	0,970	4747	1,00	111	308	0,89	0,04	7	0
Recycled cotton wool	50	31	JCAL	0,980	9271	1,00	71	174	0,57	0,035	7	0
Wood wool	40	68	JCAL	0,954	14169	1,01	54	109	0,35	0,09	8	0
Light hemp concrete	42	285	JZK	0,68	4571	3,2	309	-	-	47,5*	6*	0,35
Heavy hemp concrete	43	574	JZK	0,30	380000	2,5	5	-	-	5500*	1*	0,35
Façade wall coating	15	1775	-	-	-	-	-	-	-	3770	1*	0,2
Separation wall coating	15	1620	-	-	-	-	-	-	-	4685	1*	0,2