Caractérisations et modélisations acoustiques des granulats et tiges de Typha TyCCAO project

TyCCAO
Typha Combustible Construction Afrique de l'Ouest

Pôle BioGéo
Caractérisation acoustique/thermique des matériaux bio & géosourcés

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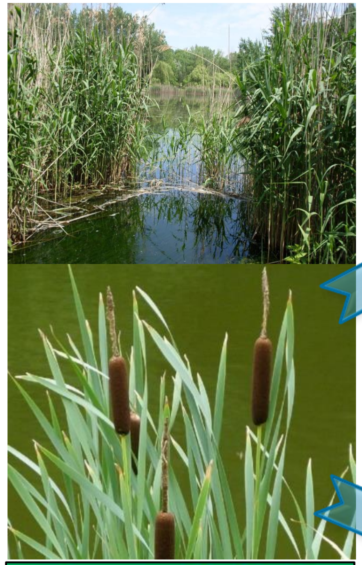
JOURNEES TECHNIQUES ACOUSTIQUE ET VIBRATIONS

Aix-en-Provence

07-08 juin 2023

Outline

Context



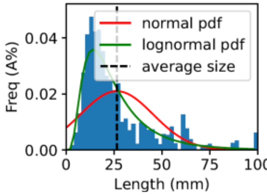
TyCCAO
Typha Combustible Construction Afrique de l'Ouest

Materials

Same batch
Elementerre SARL
Sénégal

Experimental characterizations

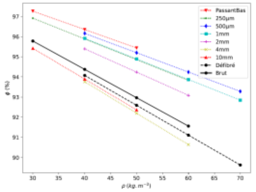
Size distributions



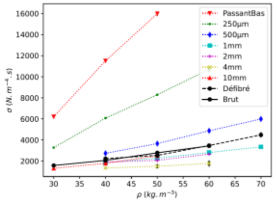
Bulk densities

Loose density
33,8 kg.m^{-3}
4,8 kg.m^{-3}

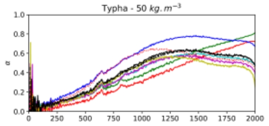
Porosity



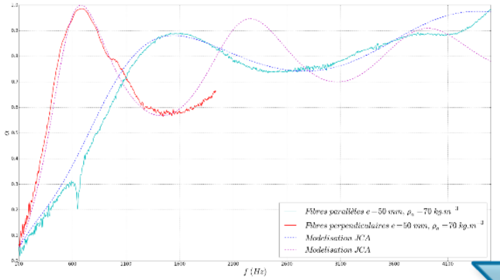
Airflow resistivity



Acoustical performances



Acoustical modelling



Ep. (mm)	Masse volumique (kg.m^{-3})	ϕ	σ ($N.m^{-4}.s^{-1}$)	α_∞	Λ	Λ'
20	54	0,94	302	1,95	$0{,}8.10^{-4}$	$1{,}9.10^{-4}$
	51	0,94	302	1,95	$0{,}8.10^{-4}$	$1{,}9.10^{-4}$
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50	72	0,92	388	3,5	$1{,}8.10^{-4}$	$3{,}0.10^{-4}$
	64	0,92	388	2,8	$1{,}4.10^{-4}$	$3{,}8.10^{-4}$
	65	0,92	388	2,8	$1{,}2.10^{-4}$	$4{,}2.10^{-4}$
100	70	0,92	372	2,8	$1{,}4.10^{-4}$	$3{,}8.10^{-4}$

Conclusions

Outline

I. Context

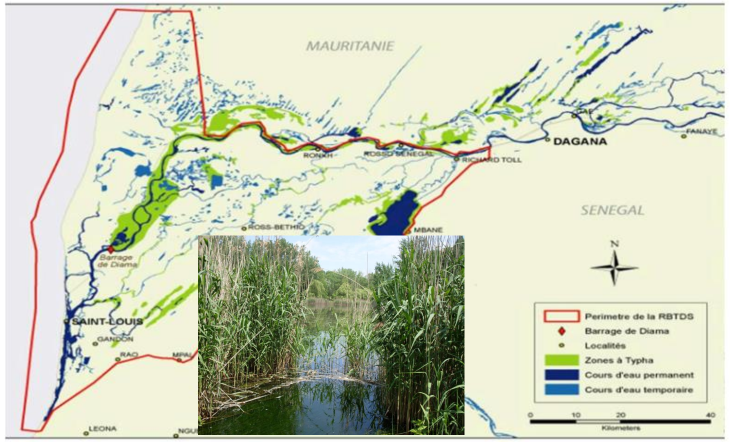
TyCCAO
Typha Combustible Construction
Afrique de l'Ouest

I. Context : an invasive plant that spreads quickly

- Typha Australis or
  Typha Domingensis (scientific name)

[www.tyccao-typha.org]

- Conditions favourable to the proliferation of typha due to the construction of dams on the Senegal River



[PNEEB/TYPHA 2014]

- Estimated average increase in the surface area covered of about 15% per year on more than 130 km of riverbanks
- Typha occupies areas estimated at between 60,000 and 80,000 hectares

- Numerous negative impacts:
  - Health
  - Economic
  - Biodiversity
  - Flood risks

[Varis & *Fraboulet-Jussila* 2002]
[Mietton *et al.* 2007]
[Kane & *Akpo* 2017]
[Kotschoubey 2017]

Measures implemented so far, based on studies and evaluations have not succeeded in curbing the spread of Typha

I. Context : a significant potential in terms of vegetal biomass

- 2 possibilities for using Typha have been identified
  - Production of energy using its combustion [Caro *et al.* 2011]
  - Use as a building material with insulating properties

The Senegalese and Mauritanian governments could contribute both to the energy transition of their countries, but also fight against the proliferation of Typha.

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Typha Combustible Construction Afrique de l'Ouest

Typha Combustible and Construction in West Africa

https://www.tyccao-typha.org/

- TyCCAO goals
  - Contribute to the ecological transition
  - Fight against global warming

  by developping
  - Renewable fuels
  - Bio-based materials based on both Typha particles and stems


- Sustainable solutions

[Pittau *et al.* 2018]

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

[Arenas *et al.* 2018]

Green building

Acoustic comfort

II. Materials

Same batch
Elementerre SARL
Sénégal

II. Materials: Typha particles and stems

- 9 variants of Typha particules studied

Raw Typha

Defibrated Typha

Typha $> 10mm$

Typha $> 4mm$

Typha $> 2mm$

Typha $> 1mm$

Typha $> 500\mu m$

Typha $> 250\mu m$

Typha low pass

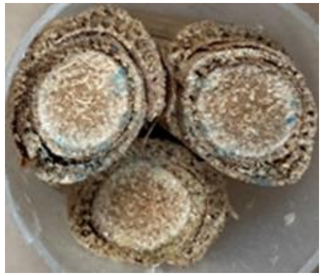
- 2 types of Typha stems

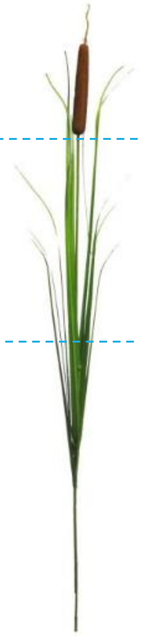
Flat stems

Parallel configuration

Perpendicular configuration

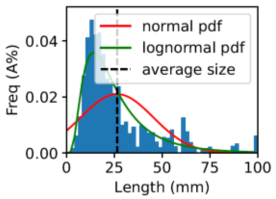
Cylindrical stems





III. Experimental characterizations

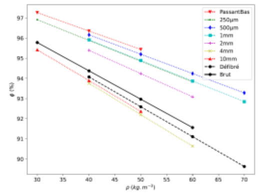
Size distributions



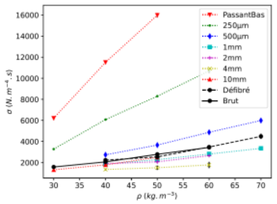
Bulk densities

Loose density
33,8 kg.m^{-3}
4,8 kg.m^{-3}

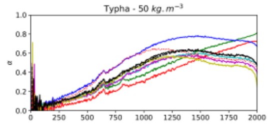
Porosity



Airflow resistivity



Acoustical performances

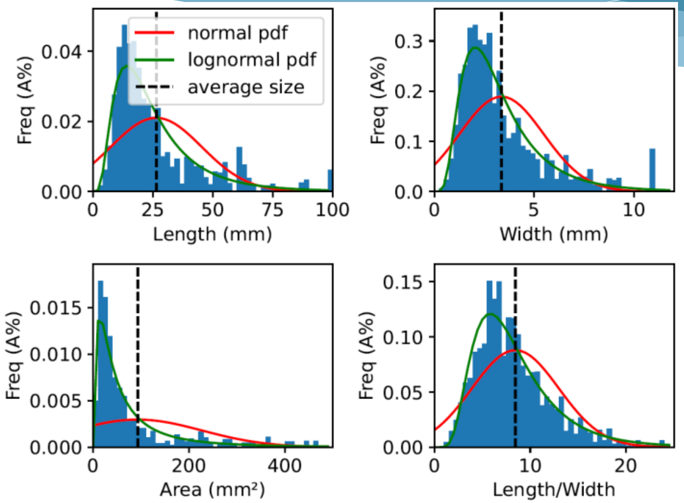


III. Experimental characterizations: Particles and stems size distributions

Granulometric analysis of defibrated Typha particles

Image analysis:

- $9.40g$ sample ↔ 2508 particles
- Resolution $130px/mm$
- Automatic image processing using Image J software



Surface weight	Normal law		Lognormal law	
	mean	Std	mean	std
Length (mm)	26,3	19,0	21,2	1,9
Width (mm)	3,4	2,1	2,8	1,8
Surface (mm²)	92,6	134,3	47,3	3,1
Length/Width	8,4	4,5	7,5	1,6

Distributions are fairly true to lognormal distributions, which is very often characteristic of the way plant particles are produced

Stems size

Characterization of an indicative representation of a batch of 200 stems

Number of stems	Mean diameter (mm)	Min diameter (mm)	Max diameter (mm)
12	11,6	3,6	20,1

Number of stems	Mean diameter (mm)	Min diameter (mm)	Max diameter (mm)
188	9,1	3,7	18,0

III. Experimental characterizations: Bulk densities

Typha particles

	Loose density	Packed density
Mean	$33,8\ kg.m^{-3}$	$51,5\ kg.m^{-3}$
Std	$4,8\ kg.m^{-3}$	$8,1\ kg.m^{-3}$

$\rho_{Typha} \ll \rho_{Hemp} /\cdot \rho_{Flax} / \rho_{wood}$

High fiber content seems acts like a spring in the mixture and prevents the particles from being compacted

Typha stems

Sample type	Diameter values (mm)	Bulk density (kg.m^{-3}) Mean	Standard dev.
With lumen (stem lower part)	$[9,5 - 20,1]$	211	21
Without lumen (stem lower part)	$[10,5 - 19,9]$	222	28
Without lumen (stem upper part)	$[3,6 - 8,4]$	202	97

Results relatively homogeneous
Samples from the upper part of the stems show a much higher standard deviation that is difficult to explain at this level of analysis

III. Experimental characterizations: Open porosity

$$\phi = 1 - \frac{\rho_a}{\rho_s}$$

[Leclaire *et al.* 2013]

Particles skeleton density

	Frame density (kg.m^{-3})	
Material	Mean	Std
Defibred Typha	675	27
Raw Typha	711	97
Typha > 10mm	655	29
Typha > 4mm	641	16
Typha > 2mm	868	65
Typha > 1mm	979	70
Typha > 500µm	1042	63
Typha > 250µm	972	47
Low pass Typha	1096	61

$\phi_{loose} = 95\%$

$\phi_{packed} = 93\%$

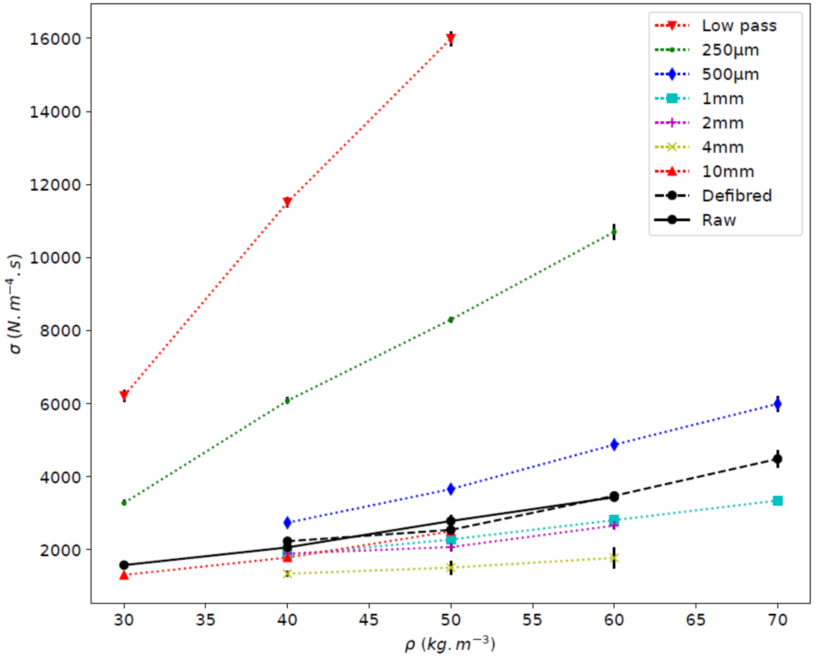
- Particles and stems skeleton denties values are consitent
- Skeletal densities are largely lower than the densities of the plant components (cellulose, lignin, pectin, etc.) which are rather of the order of 1450 kg.m^{-3} [Glé *et al.* 2021]
- Part of the porosity is not accessible with the porosimeter used (air volume comparison). This can be explained in part by the presence of very small pores

Stems skeleton density

Sample type	Frame density (kg.m^{-3})		Porosity (%)	
	Mean	Std	Mean	Std
With lumen (lower part)	757	20	72,4	1,6
Without lumen (lower part)	705	54	69,5	2,3
Without lumen (upper part)	1086	360	82,4	5,1

III. Experimental characterizations: airflow resistivity

Particles airflow resistivity



Stems airflow resistivity

Configuration stack	Thickness (mm)	Resistivity ($N.m^{-4}.s^{-1}$)
Perpendicular	20	302
Parallel	50	523
Perpendicular	53	388
Parallel	70	776
Parallel	90	672
Perpendicular	95	378

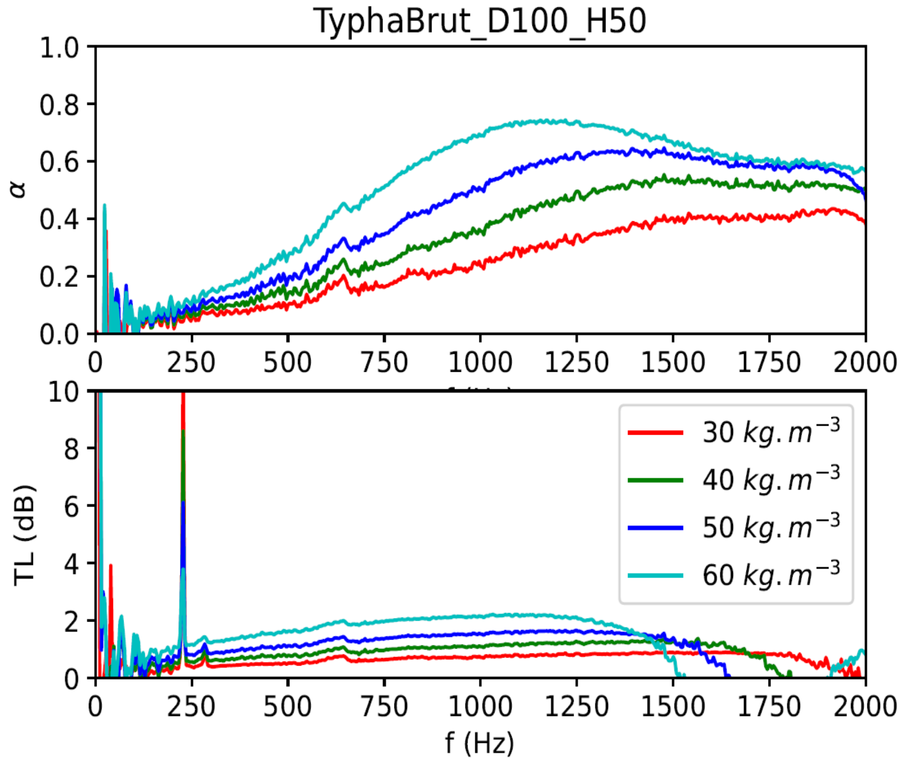
- **Results very homogeneous even though parallel config. shows very slightly higher values than the perpendicular config.**
- **Values remain relatively low, below values shown by the majority of insulating wools such as hemp, flax, kenaf, etc.**

[Piégay *et.al.* 2018]

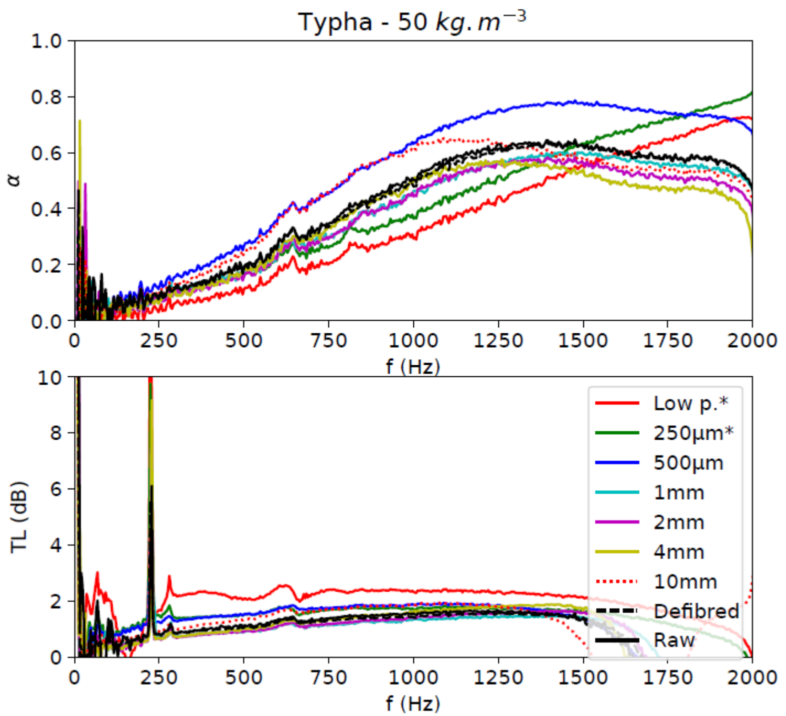
- **Increasing of flow resistance values as a function of the density**
- **The stacks made up of the smallest particles are the most resistive**
- **Very limited effect of the fibers in the resistivity value**

III. Experimental characterizations: Particules acoustical performances

- Effect of density



- Effect of particle size distribution

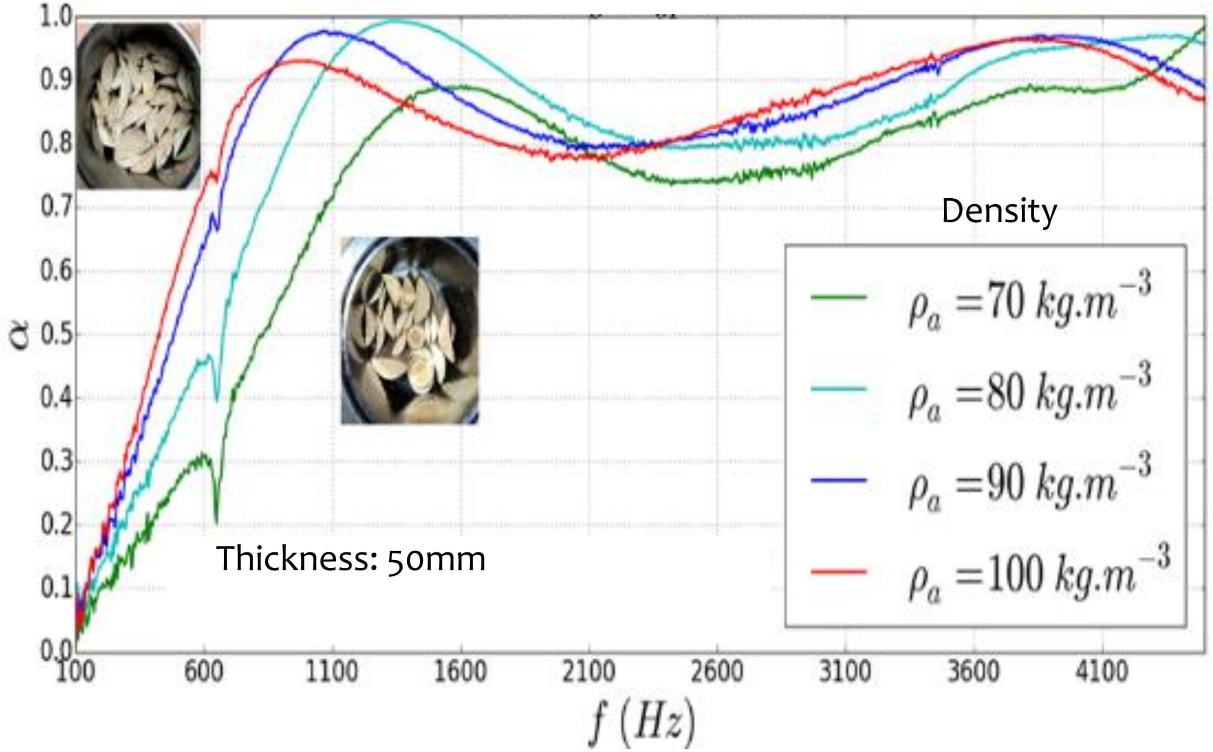


Performance levels and behaviors characteristic of vegetal granular stacks

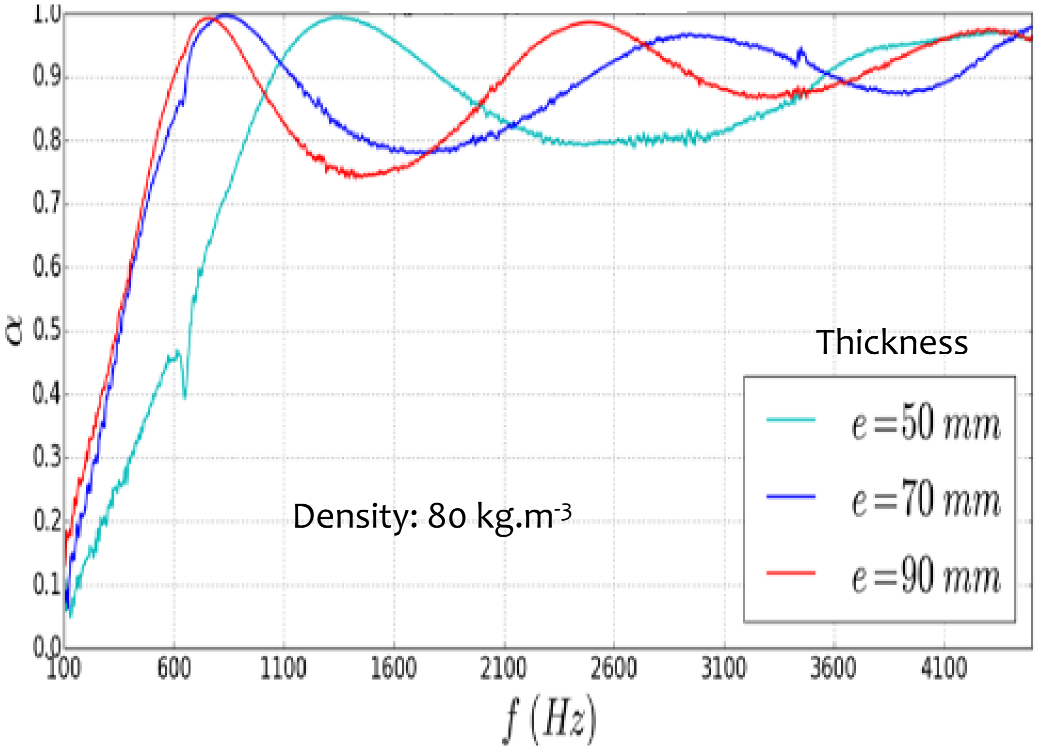
Slight increase in attenuation for finest particles (linked with resistivity) Increase of the sound absorption coefficient for fine particles up to an optimum particle size (Typha > 500 µm)

III.Experimental characterizations: Stems acoustical performances for parallel config.

- Effect of density



- Effect of thickness

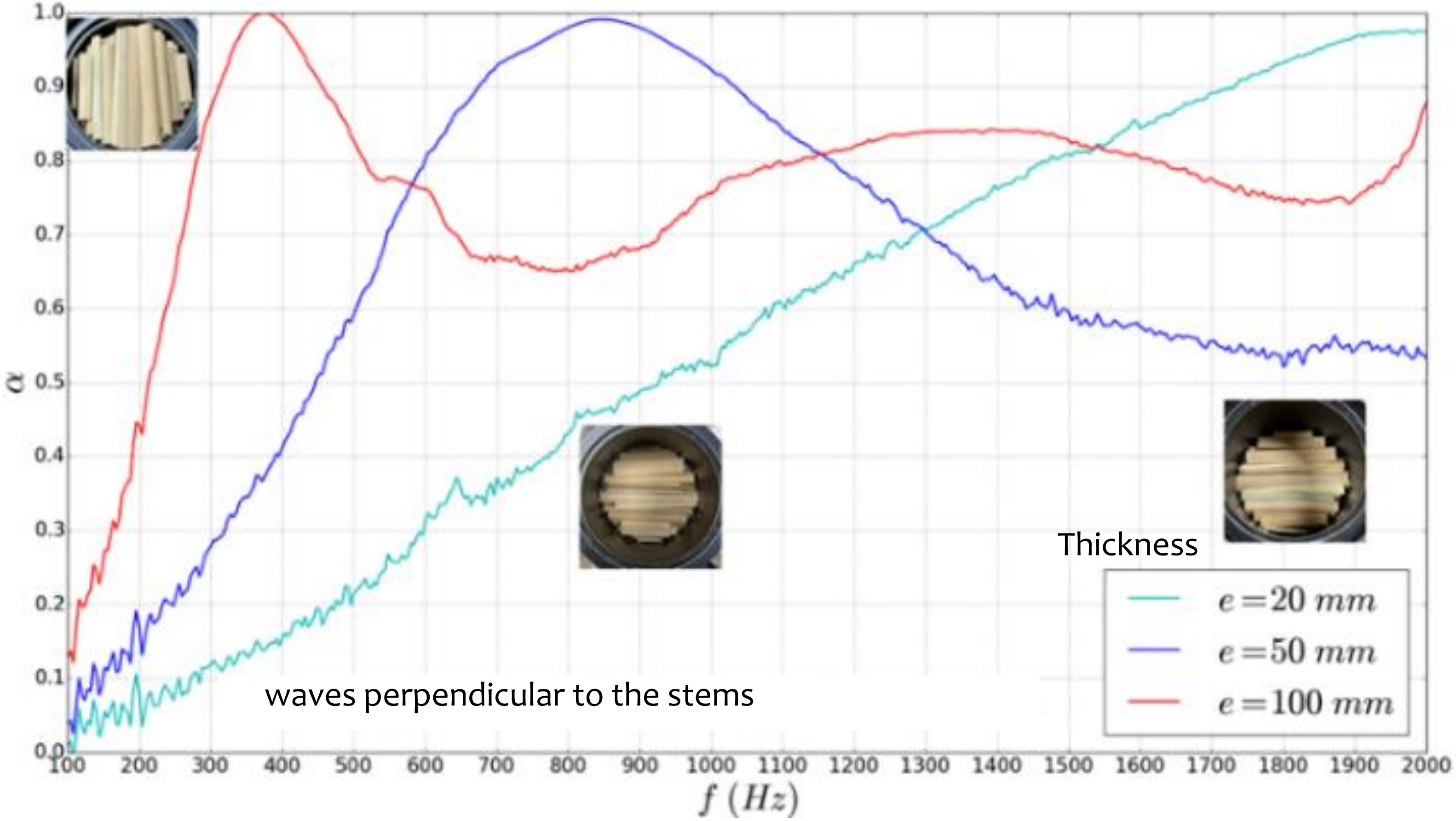


the increase in thickness will contribute to a low frequency shift of the absorption peaks

The increase in the density of the samples has the effect of shifting the absorption peaks towards the lower frequencies

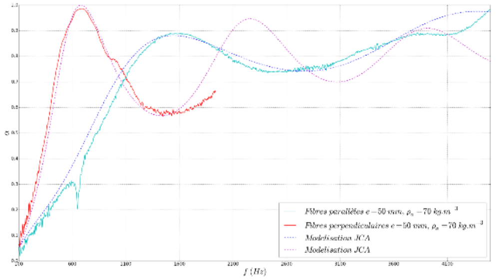
III.Experimental characterizations: Stems acoustical performances for perp. config.

- Effect of thickness



➔ **Increasing sample thickness significantly reduces the frequency of absorption peaks**

IV. Acoustical Modelling



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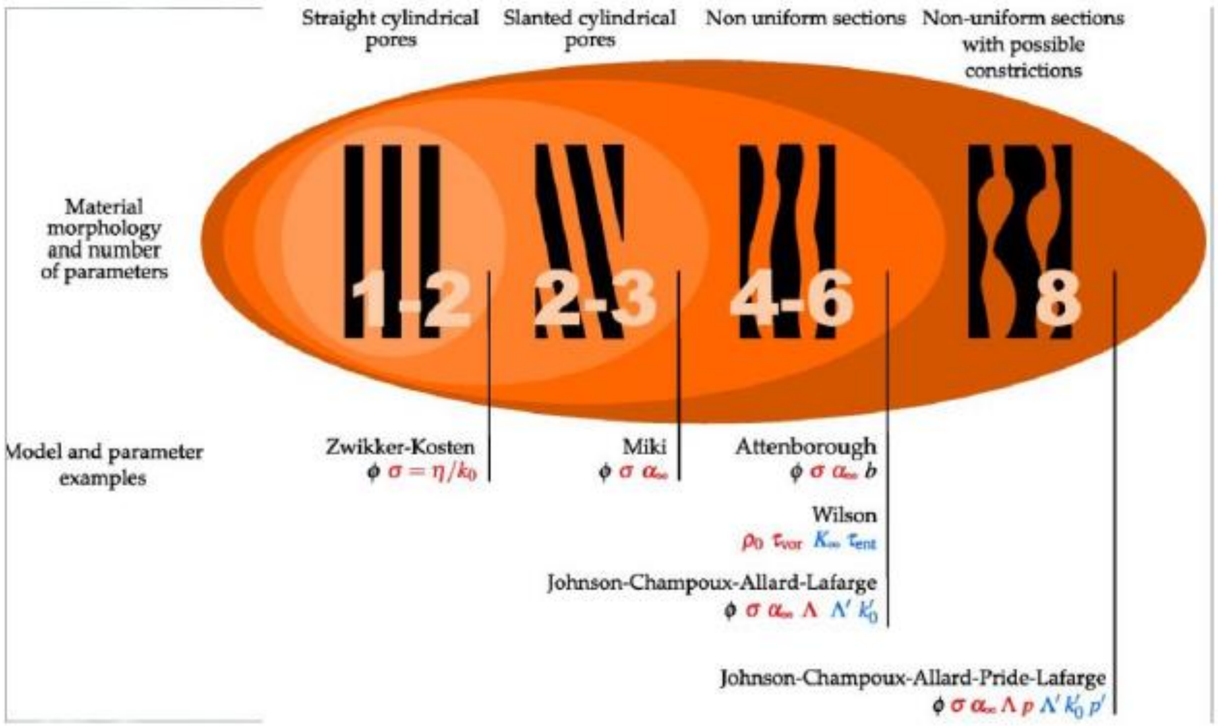
IV. Acoustical modelling: JCA / JCAL

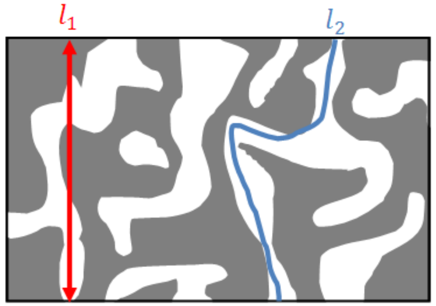
- semi-phenomenological Modelling approach based on pore geometry

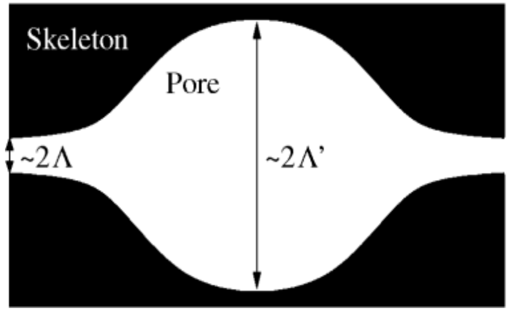


[Johnson et al. 1987]

[Champoux & Allard 1991]

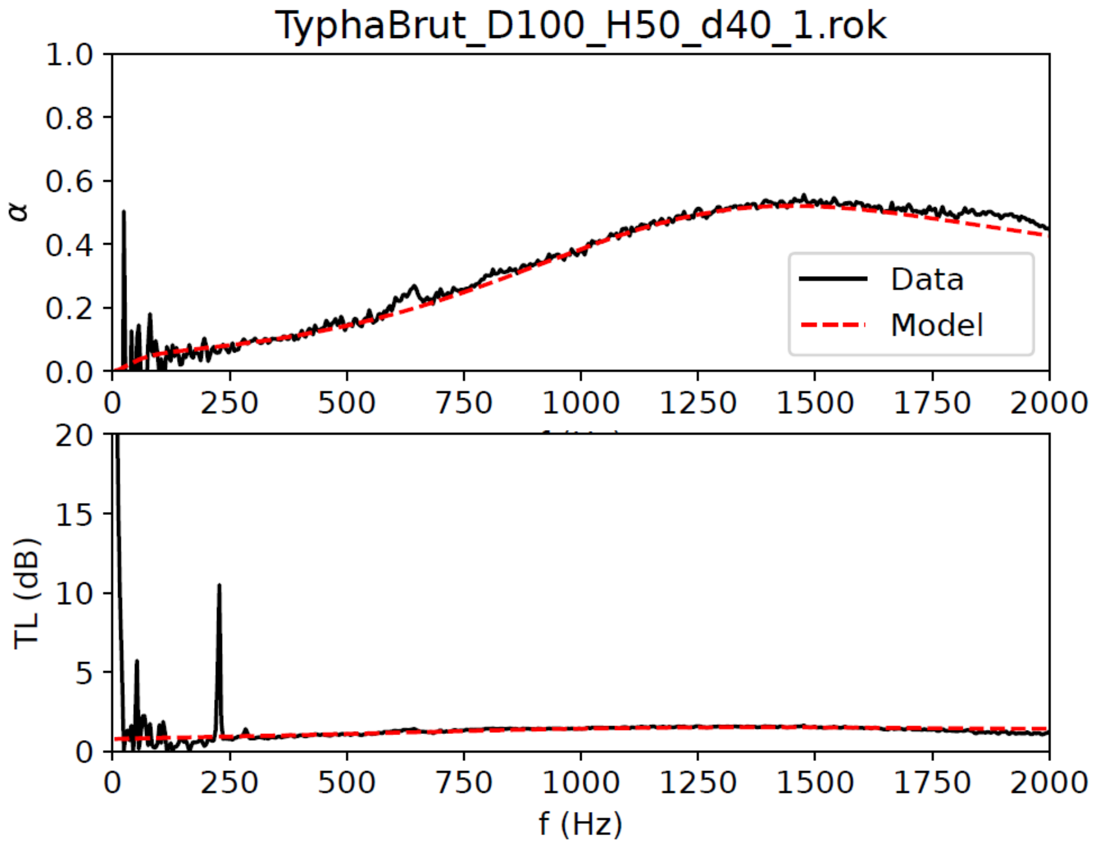
- Porosité ϕ
- Resistivité σ
- Tortuosité α_∞
- Longueur caractéristique visqueuse Λ
- Longueur caractéristique thermique Λ'
- k'_0 (JCAL) [Lafarge et al. 1997]





IV. Acoustical modelling: Particules

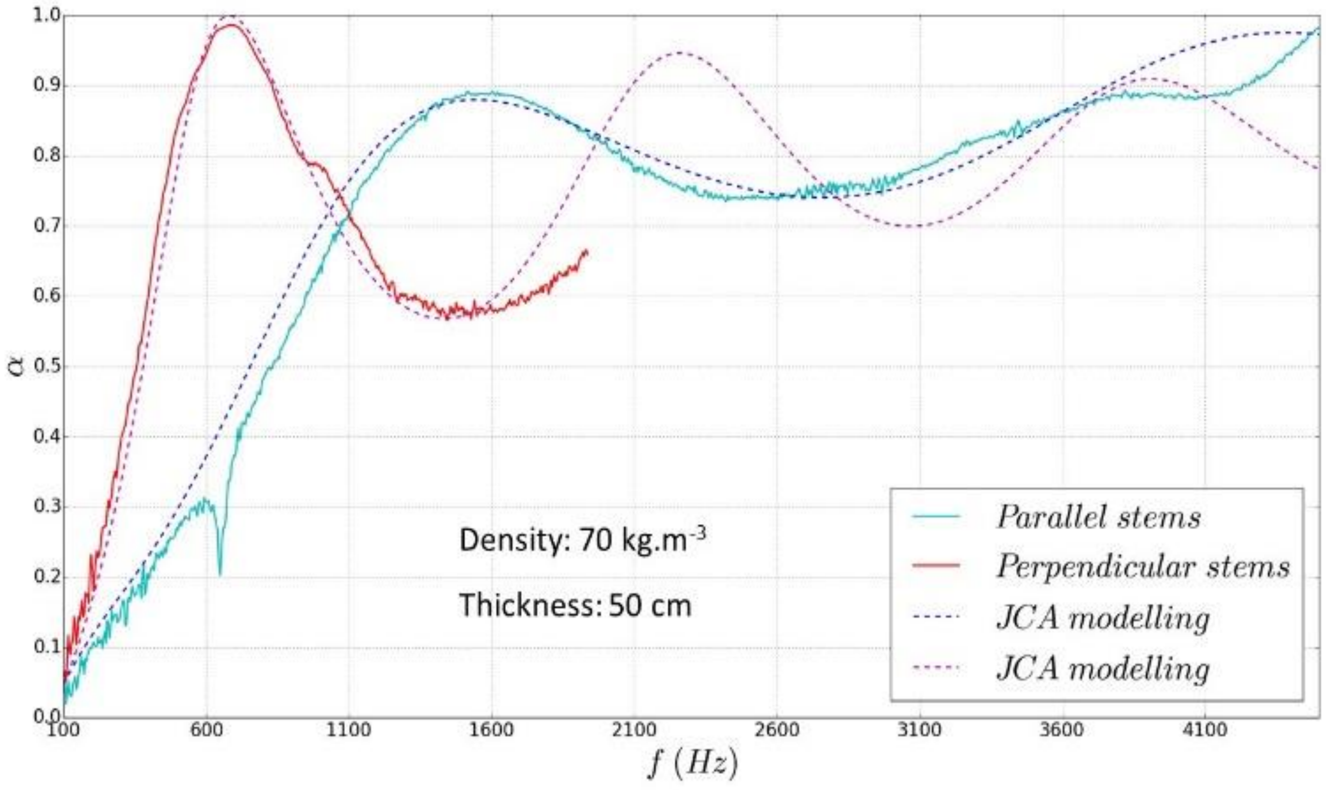
Effect of density



- **Very good agreement between model and measurement with differences of less than 5% in absorption and less than 1dB in attenuation**
- **No double porosity effects have been observed**

IV. Acoustical modelling: Stems

Effect of density



- **Very good agreement between model and measurement**
- **For a thickness of 50 mm and a density of 70 kg.m-3, the perpendicular configuration has a first absorption peak at around 650 Hz, whereas it is close to 1600 Hz for the parallel configuration**
- **The value of the acoustic absorption coefficient of this first peak is close to 1 for the perpendicular configuration whereas it is close to 0.9 for the parallel configuration**

Conclusions

- **Despite slightly atypical properties compared to more conventional vegetal aggregates such as hemp or flax shives, results show promising results in term of sound absorption level, and evidences of the effects of density, thickness, particle size and orientation on this performance**

- **The observed behavior can be modelled under a simple porosity approach for these materials with semi-phenomenological method such as JCA or JCAL modelling**

- **Further investigations will now aim at understanding the evolution of the acoustical parameters as a function of the configuration.**

Thank you for your attention

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  - http://www.umrae.fr/