Acoustics: A Tool for the Characterization of Plant Fibers and Particles

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Towards eco-friendly buildings...

Report and measures

- Building : largest consumer of energy (≈ 44% in 2007) [cgd, 2010]

⇒ Grenelle de l'Environnement, Thermal reglementations (RT 2012)

⇒ 440 milliards €≈ 535 000 jobs [Grosselin, 2011]

New requirements for materials

- A need of thermally efficient materials
- Transition towards eco-friendly materials

Key solutions

- Eco-materials, especially bio-based materials

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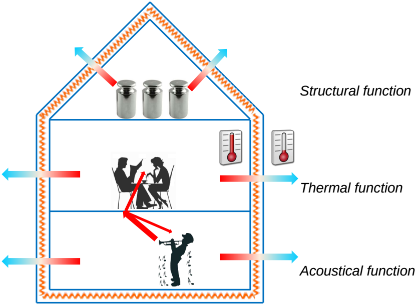

Example of hemp concrete

- A multifunctional material
  - ⇒ Thermics : λ = 0.06-0.15 $W.m^{-1}.K^{-1}$
  - ⇒ Mechanics : ρ_V = 200-800 $kg.m^{-3}$ and E = 1-100 MPa
  - ⇒ Acoustics : High α [Cerezo, 2005]
- An eco-friendly material
  ⇒ 1 m^2 stores 35 kg of CO_2 on a period of 100 years (LCA in [Boutin et al., 2005])

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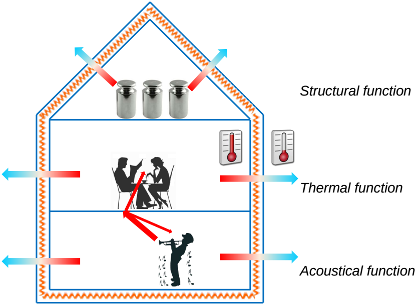

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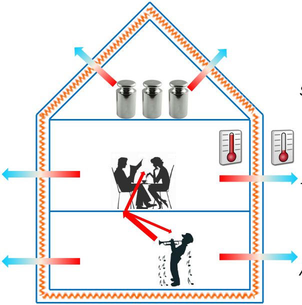

Structural function

Thermal function

Acoustical function

Hemp concrete buildings

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Hemp and products, their physical characteristics in litterature

Data of [Cerezo, 2005, Arnaud & Cerezo, 2001, Samri, 2008, Collet, 2004, Evrard, 2008, Ceyte, 2008, Placet et al., 2012] :

Plant

Particles

Parallelepipedical shape
Porosity : 57-78%
Pore size : 10-60 μm

Fibers

Cylindrical shape
Length : 5-55 *mm*
Diameter : 20-40 μm
Porosity : 2-16.2%
Pore size : 0.5-10 μm

⇒ Good thermal, modest mechanical, but mostly unknown acoustical properties...
⇒ Few litterature data describing the microstructure of hemp particles

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Data of [Cerezo, 2005, Arnaud & Cerezo, 2001, Samri, 2008, Collet, 2004, Evrard, 2008, Ceyte, 2008, Placet et al., 2012] :

Plant

Stem

Particles

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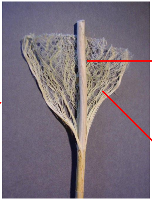

Stem

Shiv (loose particles)

Fibers

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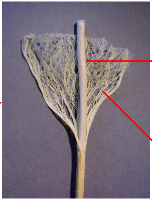

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Hemp concrete

Fibers

Hemp wool

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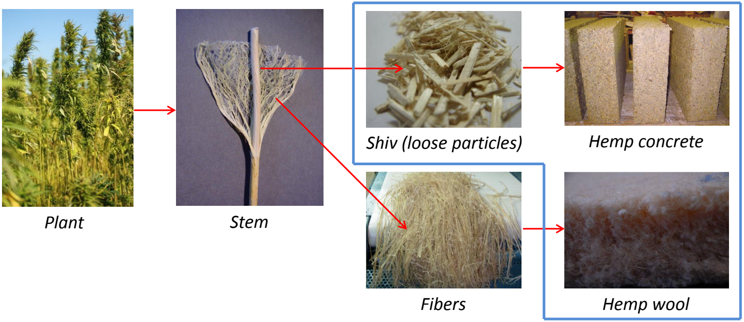

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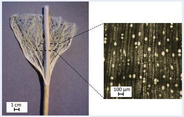
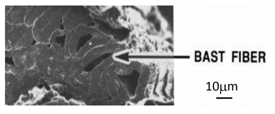
Specificities of hemp-based materials

Porous particles and fibers





[Garcia-Jaldon et al., 1998]

Anisotropy of particles

Data from [Ceyte, 2008] :

Mean length (*mm*)	4-9
Mean width (*mm*)	1-2.5
Mean thickness (*mm*)	≈0.5

Wide particle size distribution

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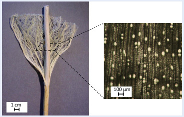

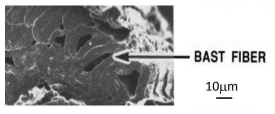

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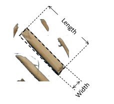

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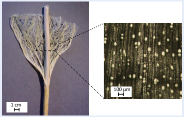

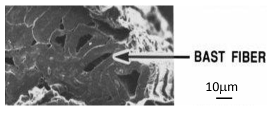

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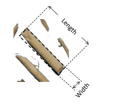

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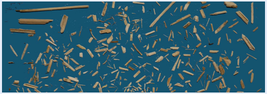
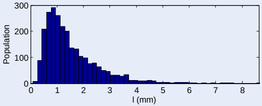
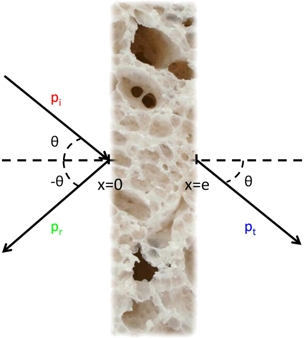




Acoustics of porous media



$$\alpha(\theta) = 1 - \left| \frac{p_r(\theta, x=0)}{p_i(\theta, x=0)} \right|^2$$

$$TL(\theta) = -10 \log \left| \frac{p_t(\theta, x=e)}{p_i(\theta, x=0)} \right|^2$$

Solid phase : Dissipation by mechanical effects

- Case of an elastic frame : Biot waves [Biot, 1956a, Biot, 1956b]
- Rigid frame hypothesis : $f > f_{dec}$ [Zwikker & Kosten, 1949]

Fluid phase : Dissipation by visco-inertial (ρ) and thermal effects (K)

$$\Delta p + \omega^2 \frac{\rho}{K} p = 0$$

- Observation level

At pore level	*At frame level*
[Johnson et al., 1987, Allard, 1993, Lafarge et al., 1997]	[Tarnow, 1996, Umnova et al., 2000, Boutin & Geindreau, 2010]

- Case of a multiscale porous network

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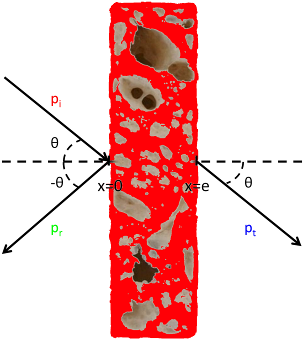

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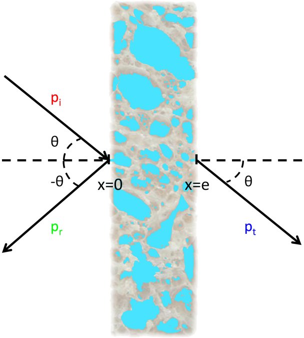

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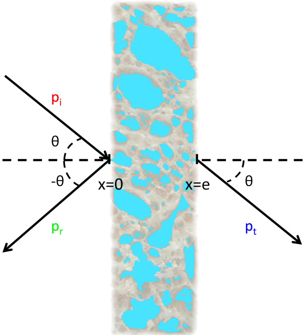

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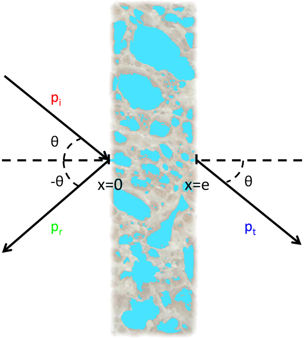

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Key Questions

? In what range are located the acoustical properties of hemp-based materials and how can we control them ?

? How can we take into account the atypical characteristics of hemp-based materials to predict and optimize their acoustical properties ?

? **Can acoustics be used as a characterization tool for this kind of materials ?**

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Approach of the thesis

Particles

Fibers

Binders

Constituents

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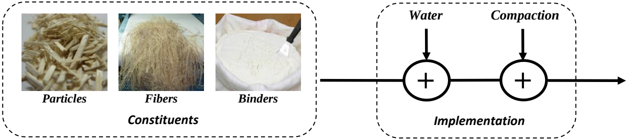

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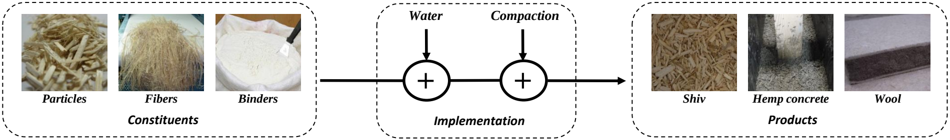

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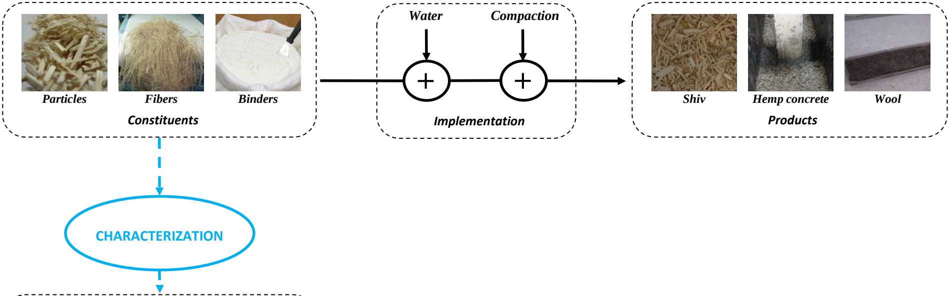

Physical characteristics of constituents

- Particle size distribution
- Apparent density
- Frame density
- Porosity
- Pore size

Approach of the thesis

Particles *Fibers* *Binders*

Constituents

Water *Compaction*

Implementation

Shiv *Hemp concrete* *Wool*

Products

CHARACTERIZATION

Physical characteristics of constituents

- Particle size distribution
- Apparent density
- Frame density
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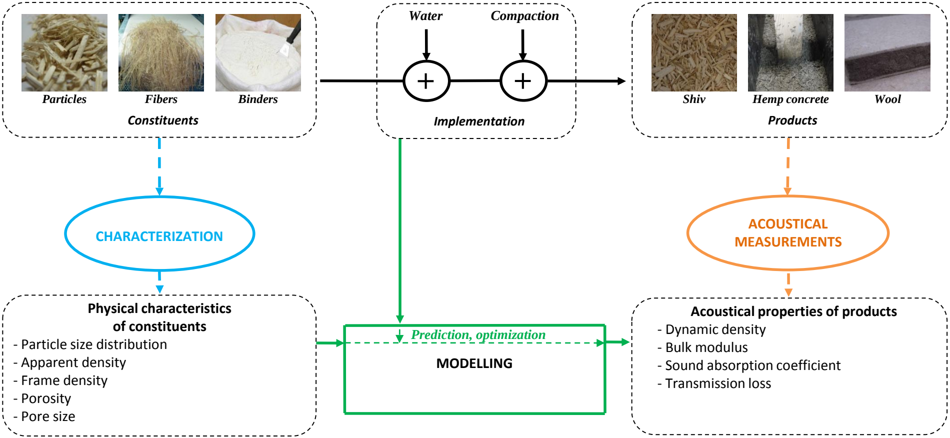
ACOUSTICAL MEASUREMENTS

Acoustical properties of products

- Dynamic density
- Bulk modulus
- Sound absorption coefficient
- Transmission loss

Approach of the thesis



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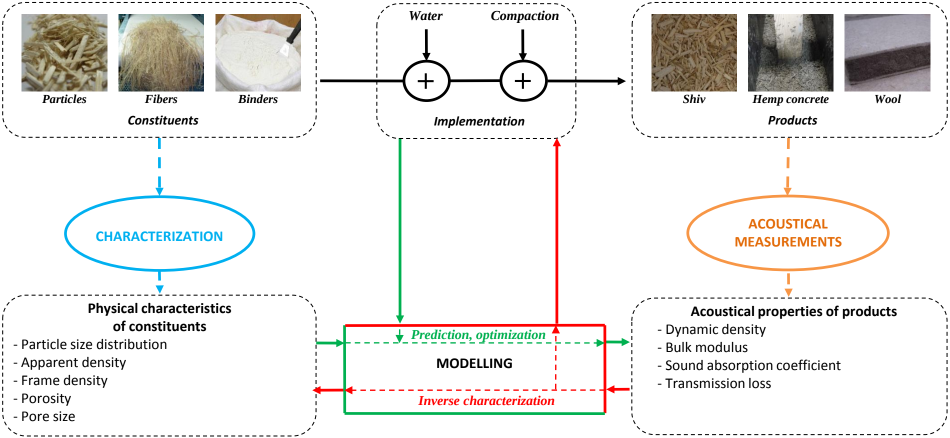

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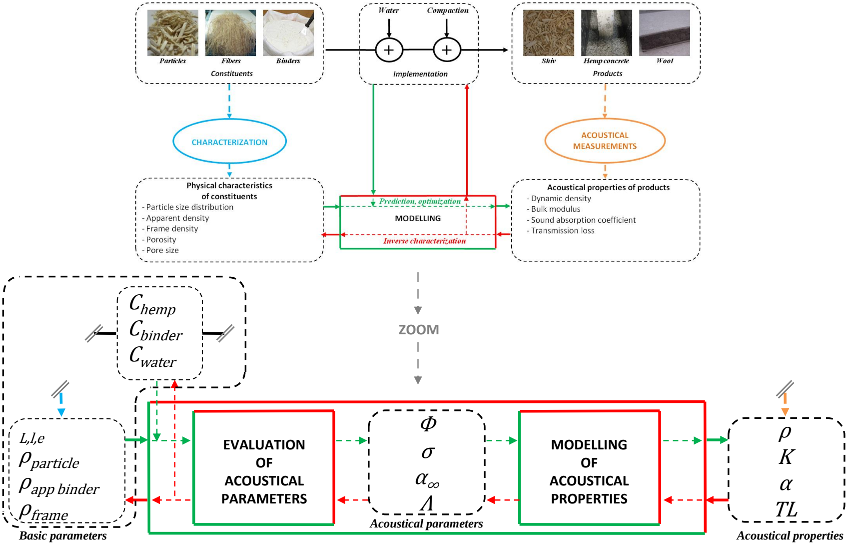
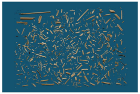
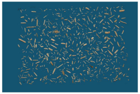
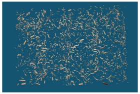
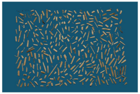
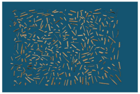
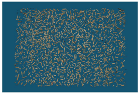
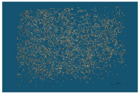


Shiv samples

Material	Picture	ρ_v ($kg.m^{-3}$)
CA		100-150
CB		100-140
CC		100-160
CD		100-140
CE		100-140
	⊢—⊣ = 10 *cm*	

Origins : LCDA, BAFA, HEMCORE, EUROCHANVRE, FNPC

Shiv samples

Material	Picture	ρ_v $(kg.m^{-3})$
CB1		80-120
CB2		90-130
CB3		90-130
CB4		100-140
CB5		110-150
	$= 10\ cm$	

Content

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Description

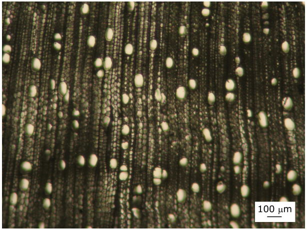
- Characteristics

	Classical beds	*Shiv*
		
Shape	Spherical	Parallelepipedical
Particle size distribution	Single-sized	Lognormal
Micro-porosity	-	57-78 %

- Multiscale porosity

Inter-particle pores

Intra-particle pores



Description

- Characteristics

	Classical beds	*Shiv*
		
Shape	Spherical	Parallelepipedical
Particle size distribution	Single-sized	Lognormal
Micro-porosity	-	57-78 %

- Multiscale porosity

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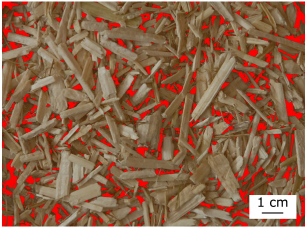

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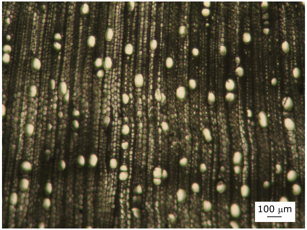

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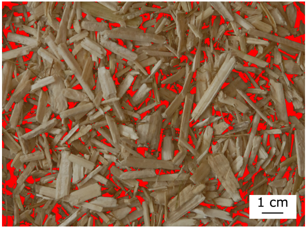

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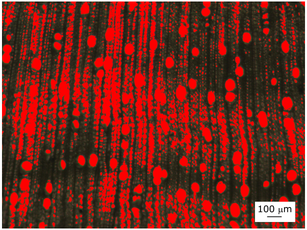
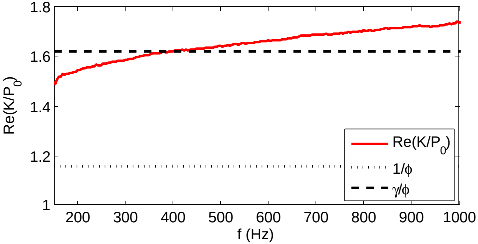


Content

Analysis of the double porosity behaviour

$\Re(\frac{K}{P_0}) > \frac{\gamma}{\phi}$

- $\Rightarrow$ Classical porous models do not work in this case
- $\Rightarrow$ Multiscale analysis
  - Intra-particles pores
  - Inter-particles pores



- Double porosity with high contrast of permeability ($F_d \approx 0$) [Olny & Boutin, 2003]
  $\Rightarrow K \approx K_{inter}$
- $\omega \gg \omega_d \Rightarrow \sigma_{intra} \gg \frac{P_0}{\phi_{intra}\omega l_{inter}^2} > 80000 N.m^{-4}.s$
  $\Rightarrow \omega_v^{intra} = O(\sigma_{intra}) \gg 80000 rad.s^{-1} \Rightarrow \rho \approx \rho_{inter}$

$\Rightarrow$ Only inter-particle pores take part in the dissipation

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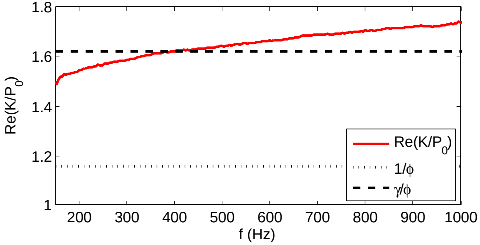

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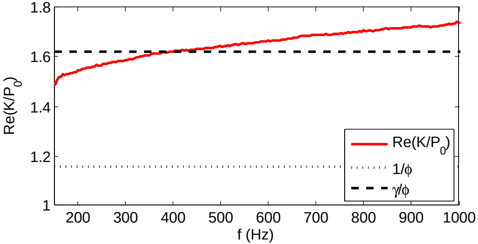

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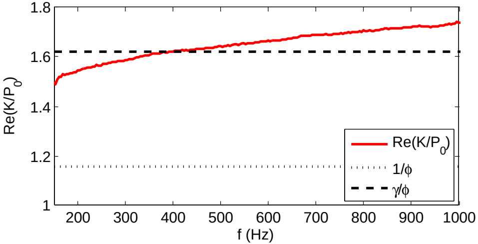

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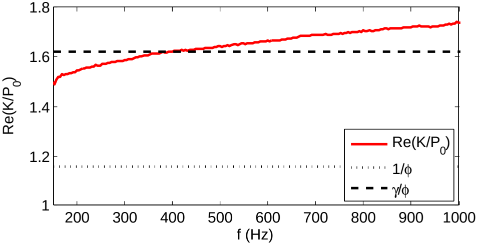

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Models used and parameters

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Rigid frame hypothesis ($f_{dec} < 20\ Hz$)

- Visco-inertial effects : [Johnson et al., 1987]
- Thermal effects : [Zwikker & Kosten, 1949]

Characterization process

1. Impedance tube measurement using three positions of microphone [Iwase et al., 1998] $[100; 2000 Hz]$
2. Measurement of ϕ [Leclaire et al., 2003] and α_∞ [Allard et al., 1994]
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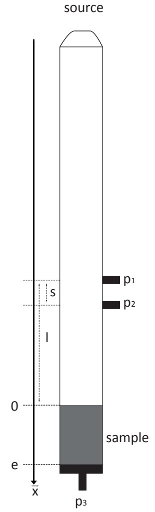

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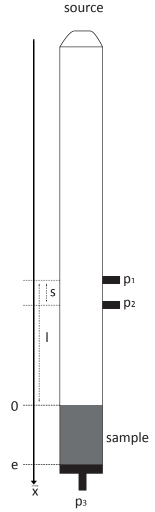
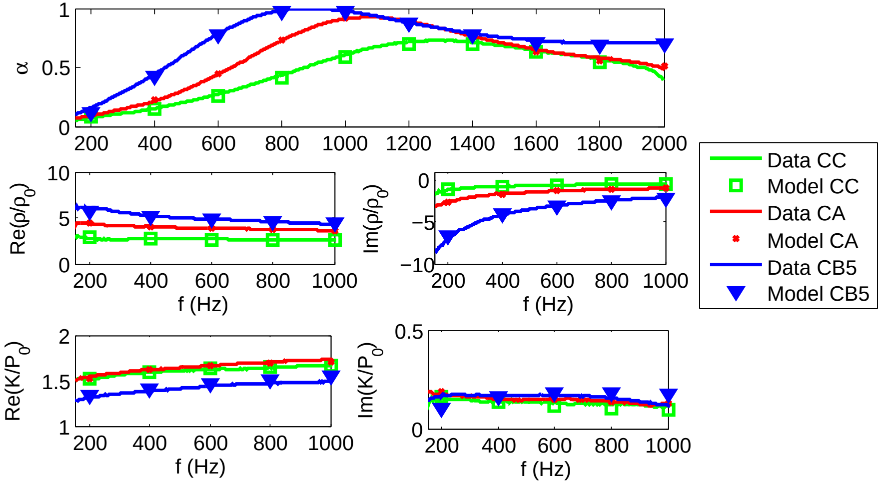


Results


α
1
0.5
0
200 400 600 800 1000 1200 1400 1600 1800 2000
Re(ρ/ρ0)
10
5
0
200 400 600 800 1000
f (Hz)
Im(ρ/ρ0)
0
−5
−10
200 400 600 800 1000
f (Hz)
Data CC
Model CC
Data CA
Model CA
Data CB5
Model CB5
Re(K/P0)
2
1.5
1
200 400 600 800 1000
f (Hz)
Im(K/P0)
0.5
0
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Content

Apparent density, porosity and thickness of particles from ϕ_{inter}

- Inter-particle porosity

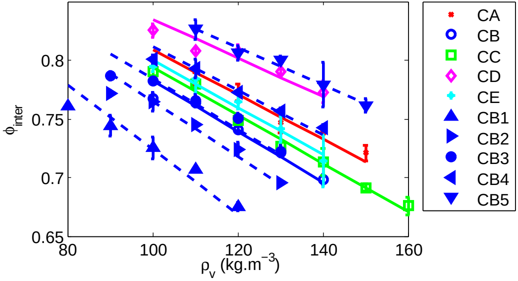
$$\phi_{inter} = 1 - \frac{\rho_v}{\rho_{particle}}$$

- Intra-particle porosity

$$\phi_{intra} = 1 - \frac{\rho_{particle}}{\rho_{frame}}$$

- Mean thickness of particles

$$\bar{E} = \rho_s / \rho_{particle}$$



Chanvres	CA	CB	CC	CD	CE	CB1	CB2	CB3	CB4	CB5
$\rho_{particule}$ $(kg.m^{-3})$	523	460	486	605	499	362	425	463	531	633

See : Glé, Gourdon, Arnaud. *Modelling of the acoustical properties of hemp particles*, Const. Build. Mat., 2012

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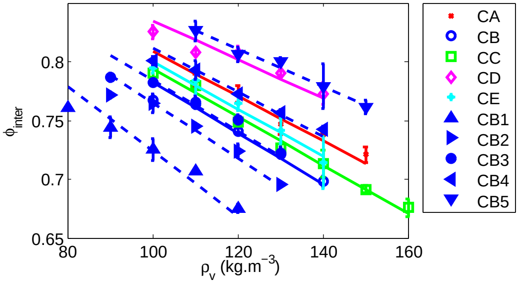

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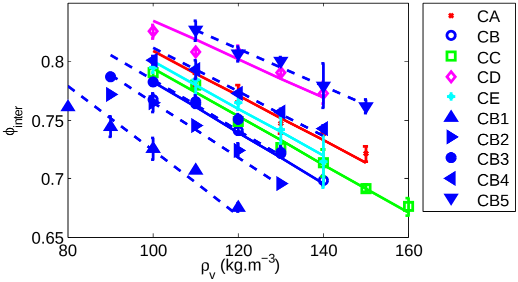

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Identification of a characteristic particle size from σ

- Empirical and theorical granular models

[Attenborough, 1993, Prieur du Plessis & Woudberg, 2008, Voronina & Horoshenkov, 2003, Umnova et al., 2000, Boutin & Geindreau, 2010]

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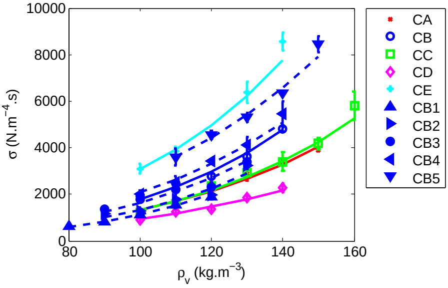

⇒ Can yield to an estimate of the particle size $R_{particle}$

⇒ Results with Boutin & Geindreau model

Shiv	CA	CB	CC	CD	CE	CB1	CB2	CB3	CB4	CB5
$R_{particle}$	384	389	421	384	268	688	502	404	302	208

⇒ Correlation between $R_{particle}$ and $\bar{E}$ (mean thickness)

$$R_{particle} = 0.642\bar{E} + 0.130 \qquad (R^2 = 0.939)$$

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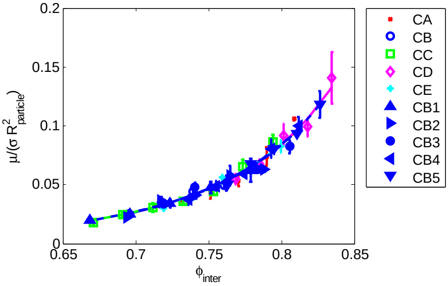

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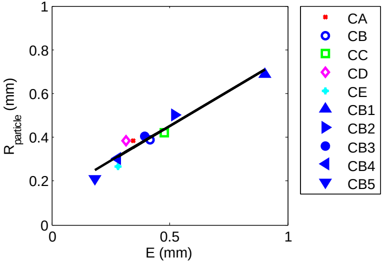

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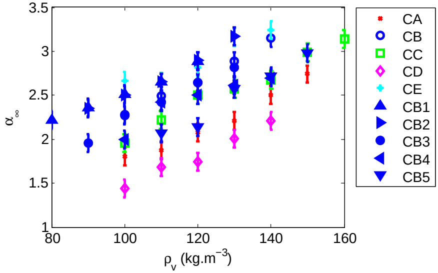

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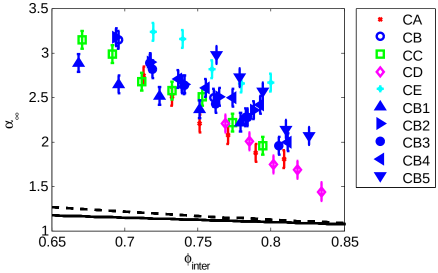

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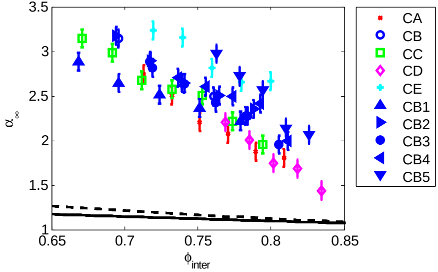

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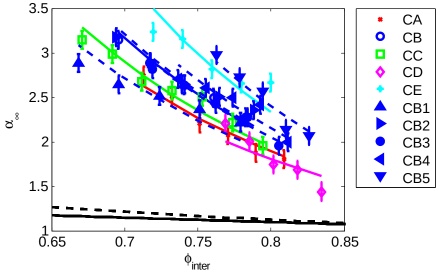

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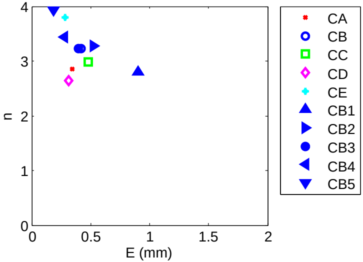

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Investigation of the variability of particles characteristics

- Sources of variability
  - Environment parameters
    - Weather and climate
    - Ground properties and history
  - Cultivation parameters
    - Planting
    - Harvesting
    - Post-treatment
- Experimental program
  - 50 shiv from FNPC (2009 → 2011)
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- Approach
  1. Experimental characterization
  2. Evaluation of (ϕ_{inter}, σ, α_{∞}, Λ)
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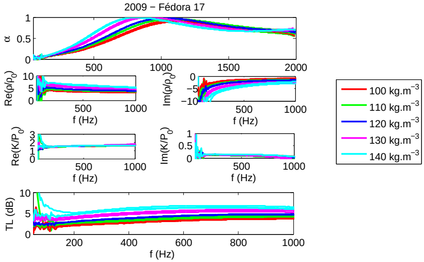

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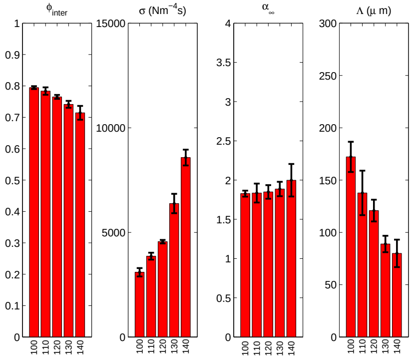

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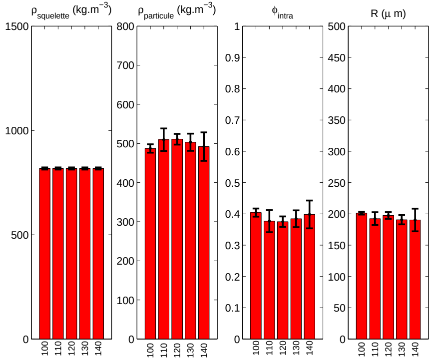
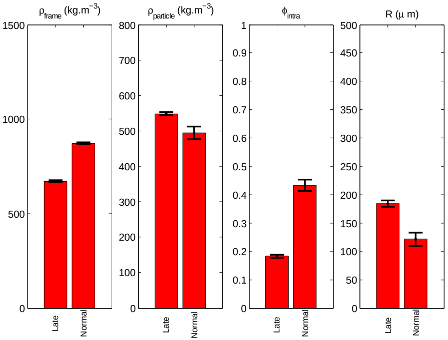


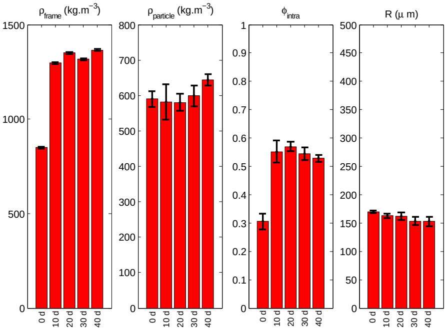
Cultivation parameters : Planting

- Planting date
  ⇒ Significant effect on density, porosity and particle size



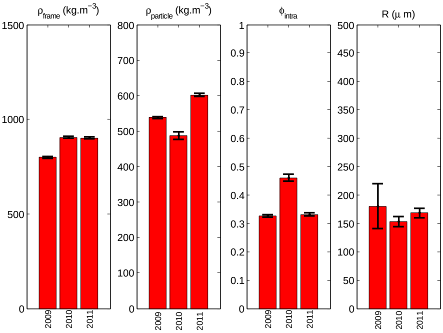
Cultivation parameters : Harvesting

- Retting
  ⇒ Significant effect on frame density and porosity



Environment parameters : Meteorological aspect

- Evolution between 2009 and 2011
  ⇒ Signifiant effect on density, porosity and particle size
- Meteorogical data
  ⇒ 2010 more wet and sunny



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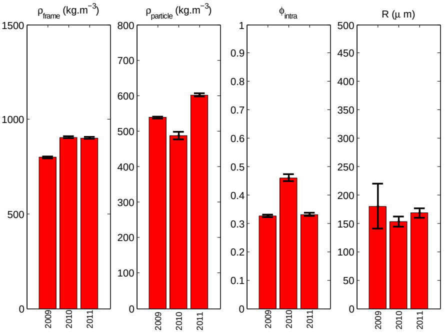

Content

Conclusions and Outlooks

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✓ Wide range of acoustical properties

✓ ϕ_{intra} masked by ϕ_{inter}

✓ Characterization of microstructure from acoustical data

✓ Effect of shape and size distribution of particles

- Outlooks

↪ Comparison of acoustical characterization with imagery data

↪ Further investigation for high binder contents

↪ Effect of anisotropy of shiv

↪ Extension to other kind of particles

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Thank you for your attention !

Acoustics: A Tool for the Characterization of Plant Fibers and Particles

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May 23rd, 2013

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