Noise and vibration control in aerospace composite structures

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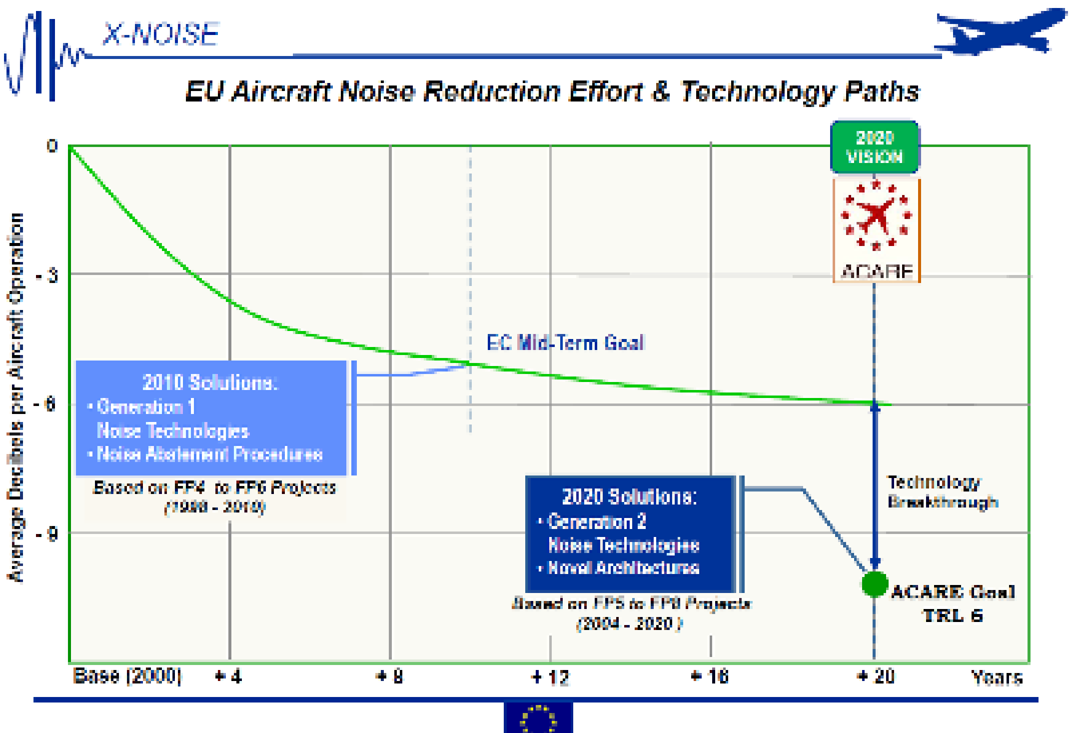
Sustainable aviation

Fuel efficient engines and lighter structures

Reduced noise pollution around airports

Acceptable noise and vibration levels inside aircraft cabins

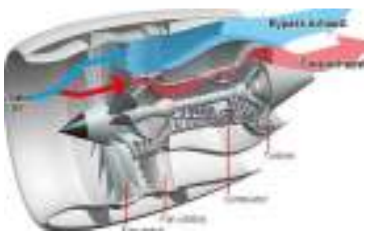


http://www.cdti.es/recursos/doc/eventosCDTI/Aerodays2011/6E1.pdf

Innovative solutions

- Intelligent use of added mass
- Increase structural damping
- Reduce noise level
- Reduce emissions
- Increase the payload

Engine noise and vibration



Aero Technologies LLC

Main noise and vibration sources in aircraft

- Engine (fan, turbine, jet)
- Interaction fluid-structure
- Hydraulic systems
- Landing gear

Structural vibrations

- Propagation through aircraft fuselage
- Propagation through flooring system

Structure-borne noise

- Transmission in solid structures (fuselage, flooring systems)
- Radiation from vibrating structures

Airborne noise

- Displacement of mass particles in the air (cabin)

Engine noise and vibration

<u>Main objective</u>: Reduce the noise and vibration level in aircrafts without detrimental impact on its composite structures

Acting on source

<u>Reduced noise level</u>

- Reduce noise level inside cabin
- Reduce noise annoyance to communities
- Mechanism: **Acoustic absorption**

Acting on media

<u>Reduced vibration level</u>

- Reduce noise level inside cabin
- Increase structure durability
- Mechanisms: **Mechanical damping and acoustic transmission barrier**

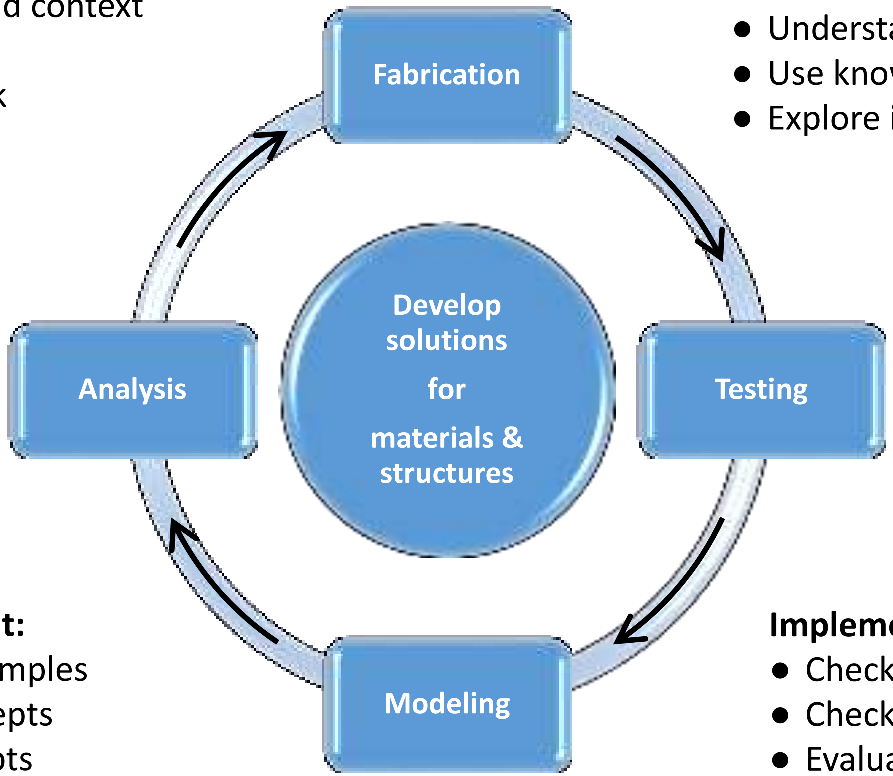
Development process

Start from the beginning:

- Define the problem quantitatively
- Understand the needs and context
- Limit the domain
- Define statement of work
- Identify people
  (Controlled goods)

Investigation:

- Define requirement specifications
- Understand technical parameters
- Use knowledge and expertise
- Explore innovative ideas



Small scale development:

- Fabricate lab demo samples
- Test preliminary concepts
- Select solution concepts
- Model concept and optimize
- Validate final concept

Implementation:

- Check for air worthiness
- Check for certification
- Evaluate impact on performance
- Develop integration procedures
- Complete proof of concept

Micro-Characterization

NSERC-Safran chair on 3D composites for aerospace

Micro-characterization thermosets ⟷ Mechanical and dynamic testing ⟷ Manufacturing and prototyping

DMA

MDSC

Pressclave with acquisition system

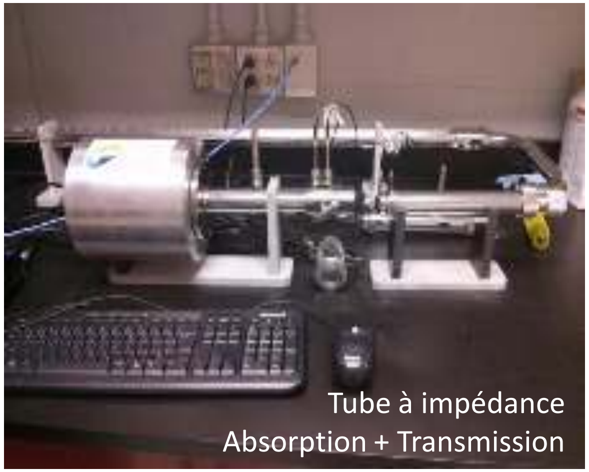
HP TGA-FTIR spectrometer

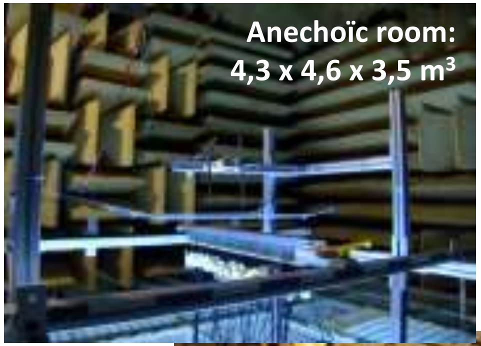
Rheometer

DMA-450 Metravib

Laboratory for acoustic and vibration analyses (LAVA)

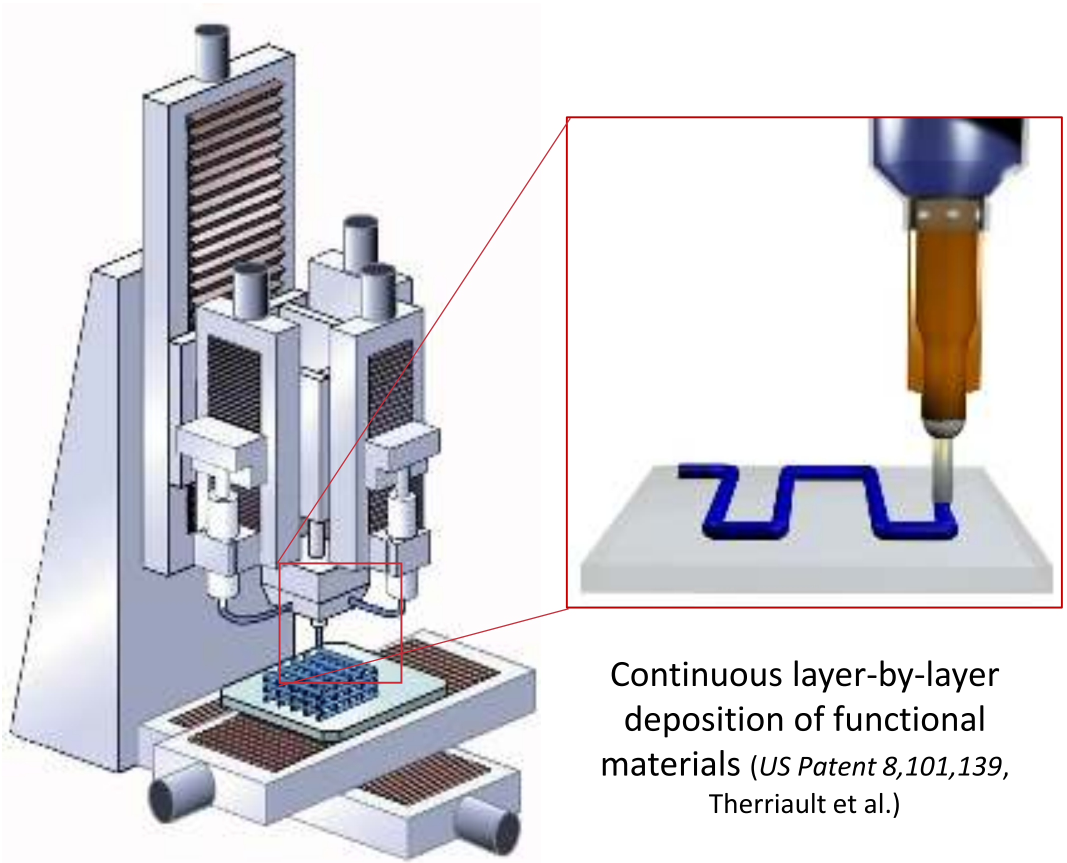
Vibration ⟷ Acoustics ⟷ Vibro-acoustics





Additive manufacturing

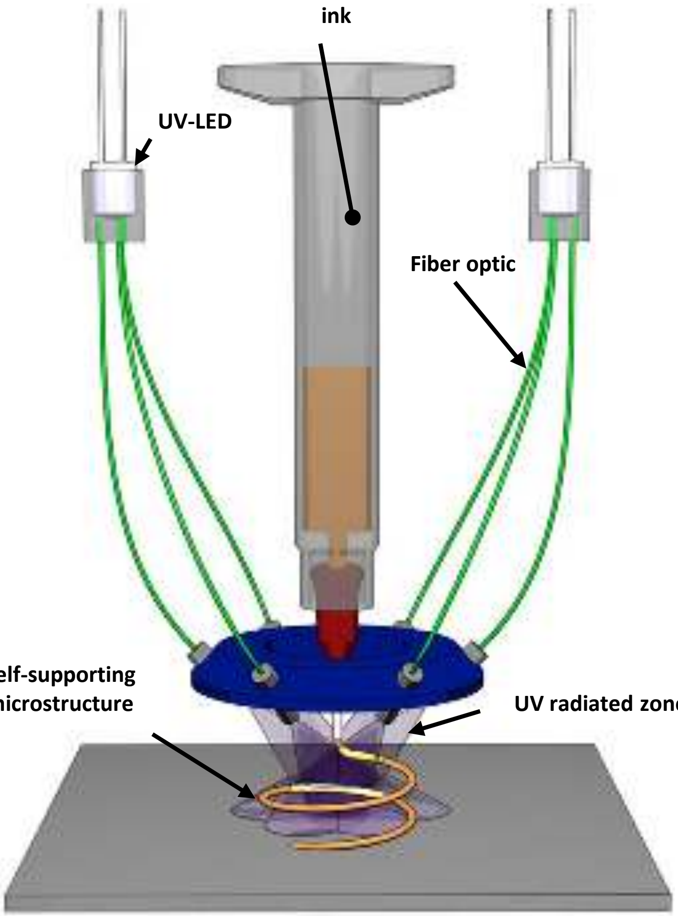
Laboratory of multiscale mechanics (LM2)



Continuous layer-by-layer deposition of functional materials (*US Patent 8,101,139*, Therriault et al.)

3D printing of complex microstructures

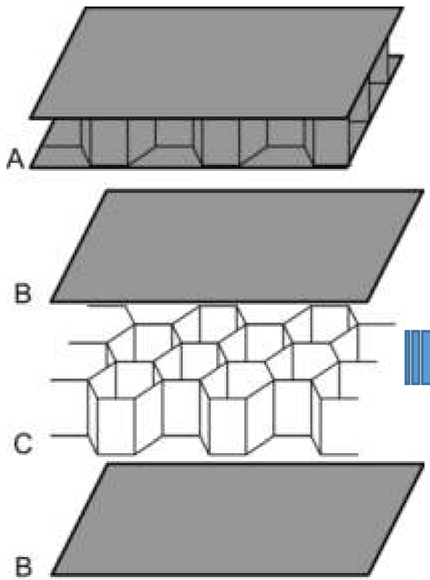
(Lewis, White, U of Illinois at Urbana-Champaign)



UV assisted freeform 3D printing

(L. Laberge Lebel)

Motivations



Sandwich structure

Blades
Flooring systems
Fuselage
Helicopter doors
ceiling

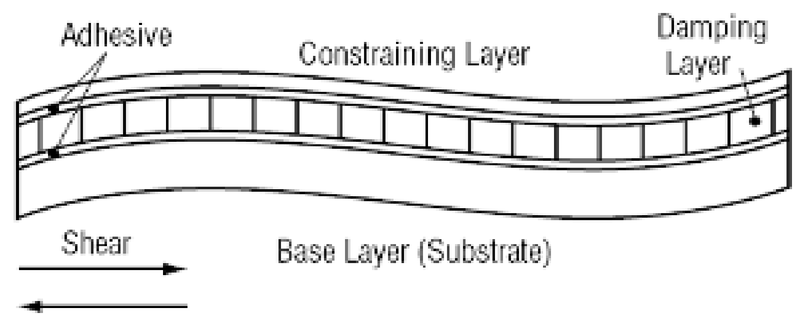
- High flexural stiffness/weight ratio
- Applications in transportation industry

- Transmission of mechanical and acoustic vibrations
- Discomfort or mechanical damages

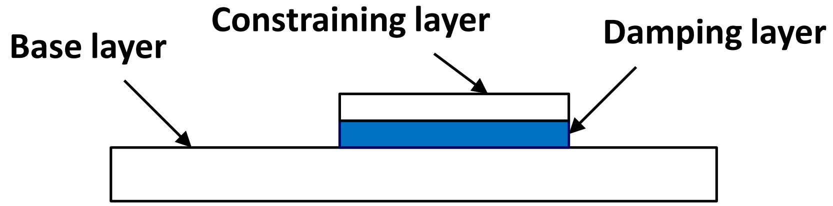
Structural Vibration

Passive damping

CLD



Constrained layer damping (CLD)



Partial constrained layer damping (PCLD)

Shearing of viscoelastic material through flexural motion of the structure

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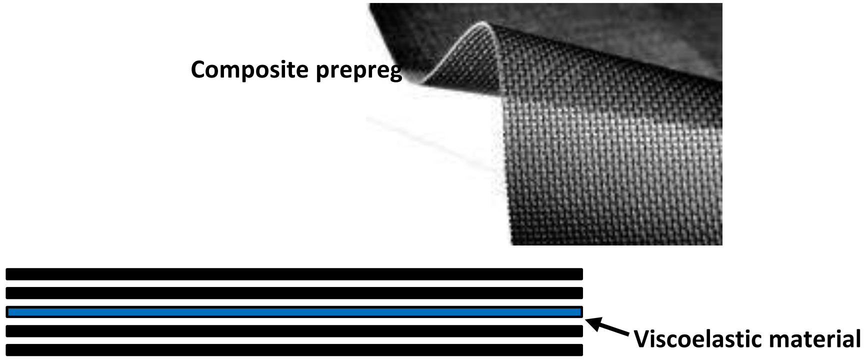
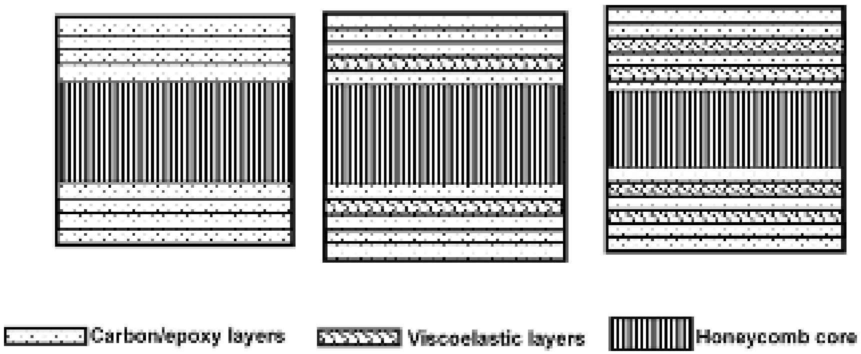
Damping increase through energy dissipation

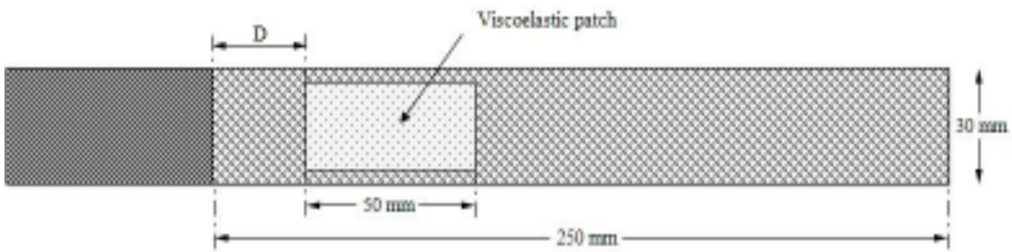
Passive damping (face sheets)

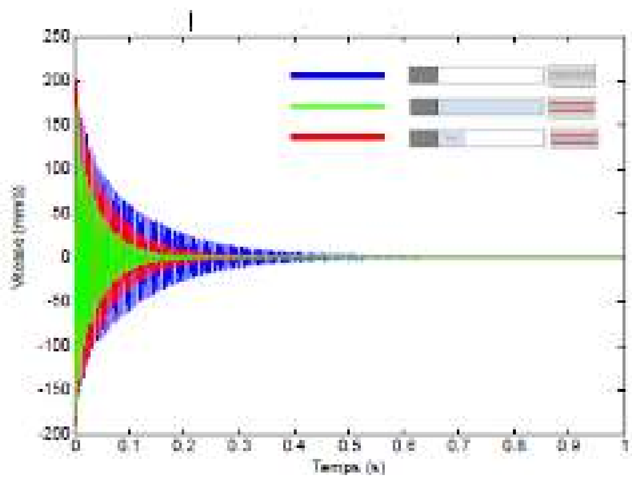




- Take advantage of the laminated structure of composite
- Interleaved viscoeclastic material
- Insertion of viscoelastic material before curing
- Limited risk of delamination

- Variable position viscoelastic material through the thickness
- Multiple shearing locations

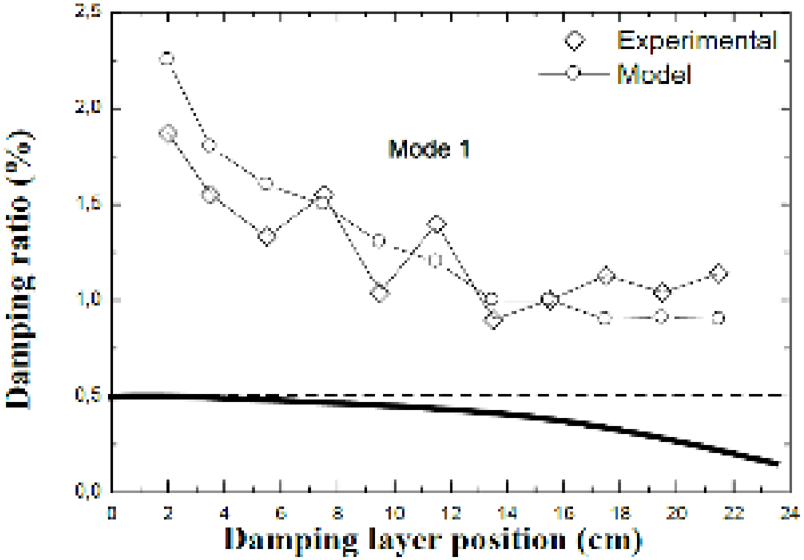


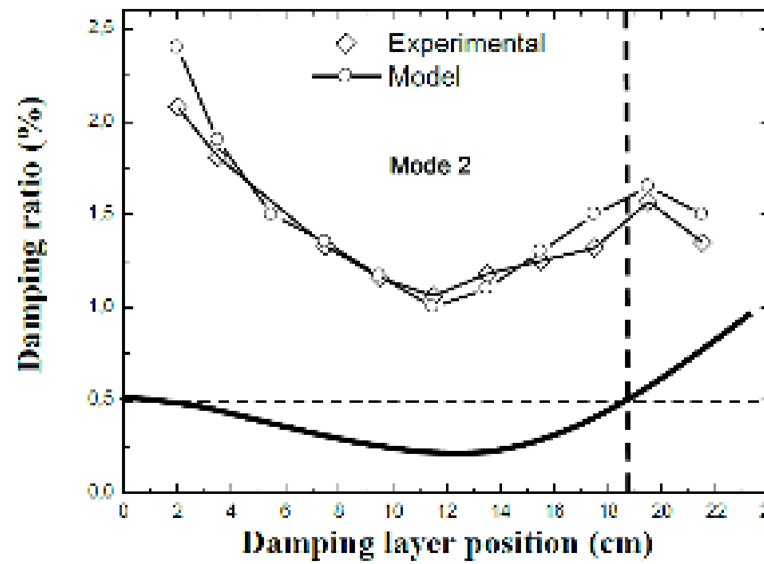


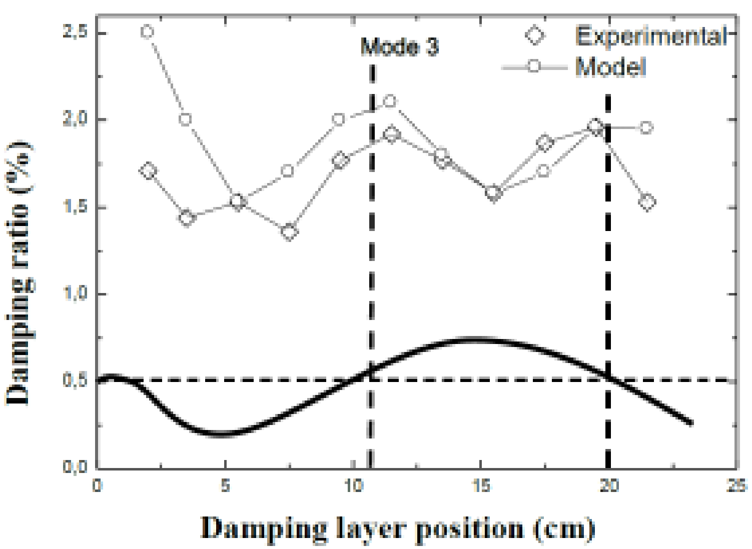
- Multiple positions along the structures
- Target areas of maximum deformation (modal node**)**

Structural Vibration

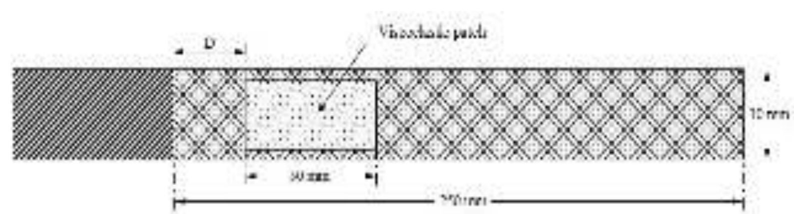
Experimental vs model





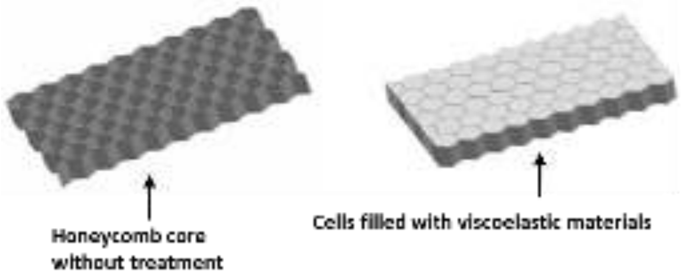


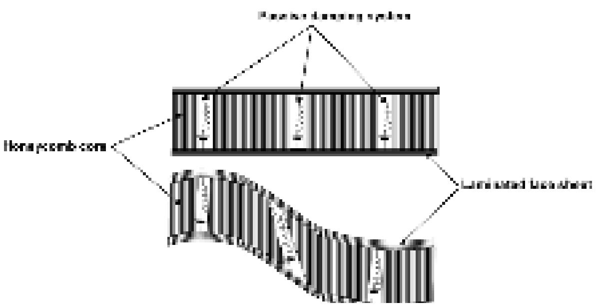
Increase of damping ratio at the modal nodes

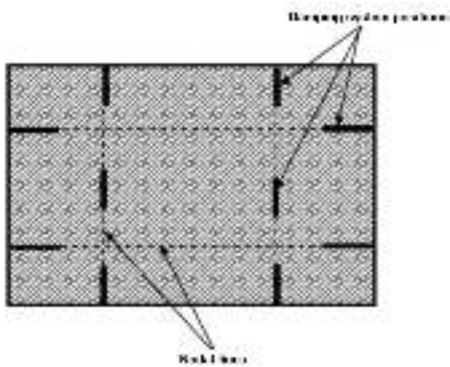


Fotsing et al, Lightweight viscoelastic damping treatment of composite sandwich beams: experimental analysis, Journal of composite materials, 47 (12) 2013 , 1501-1511

Passive damping (core)







- Core stiffness modification
- Cells filled with viscoelastic materials
- Embedded damping device in the core
- Metamaterials in the core

↓

Mapping of the whole structure along the nodal lines (high shear deformation)

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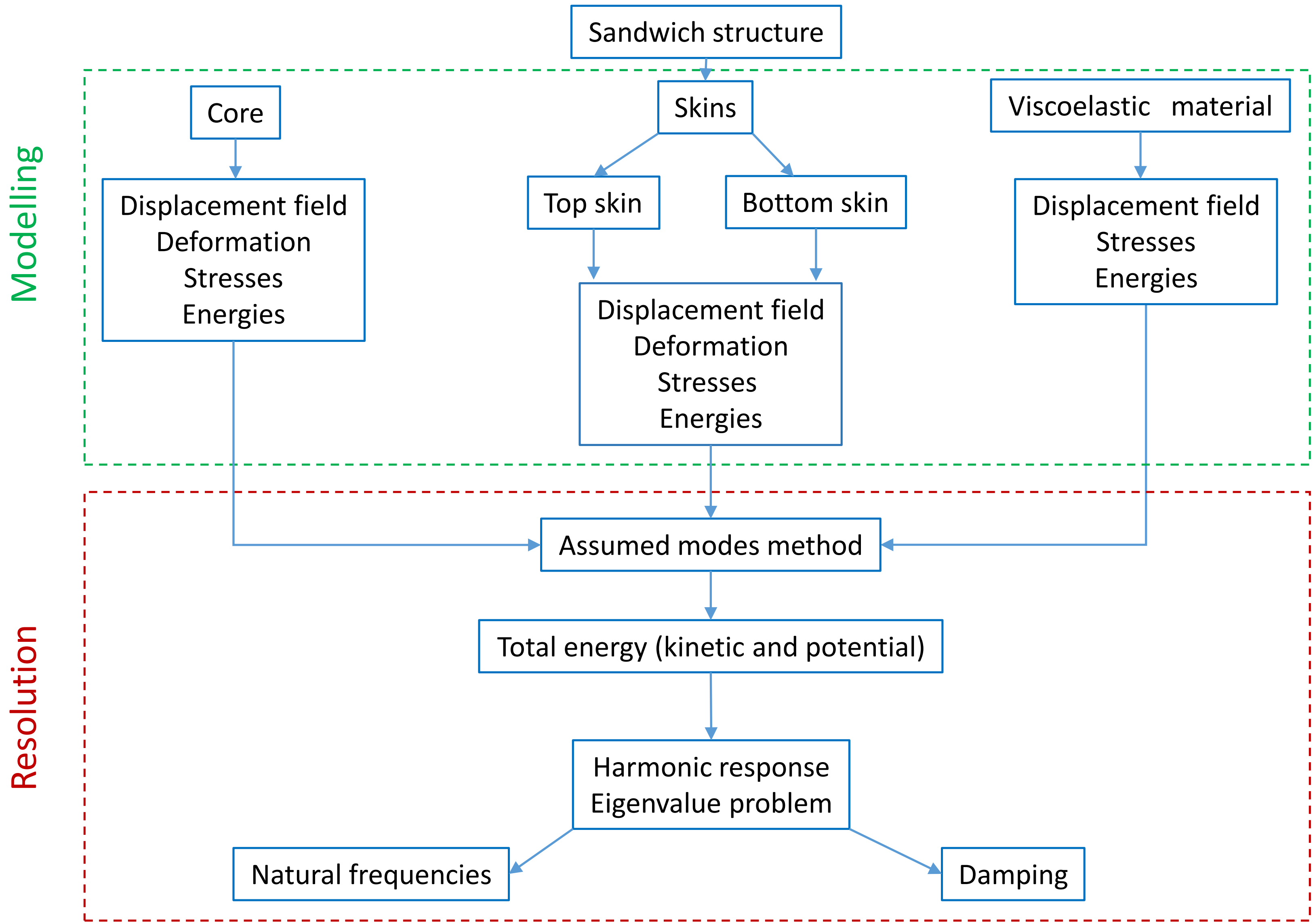
- Increase of structural damping
- Increase of acoustic transmission loss
- Reduction of the added mass

Risk of altering locally the mechanical properties of the structure

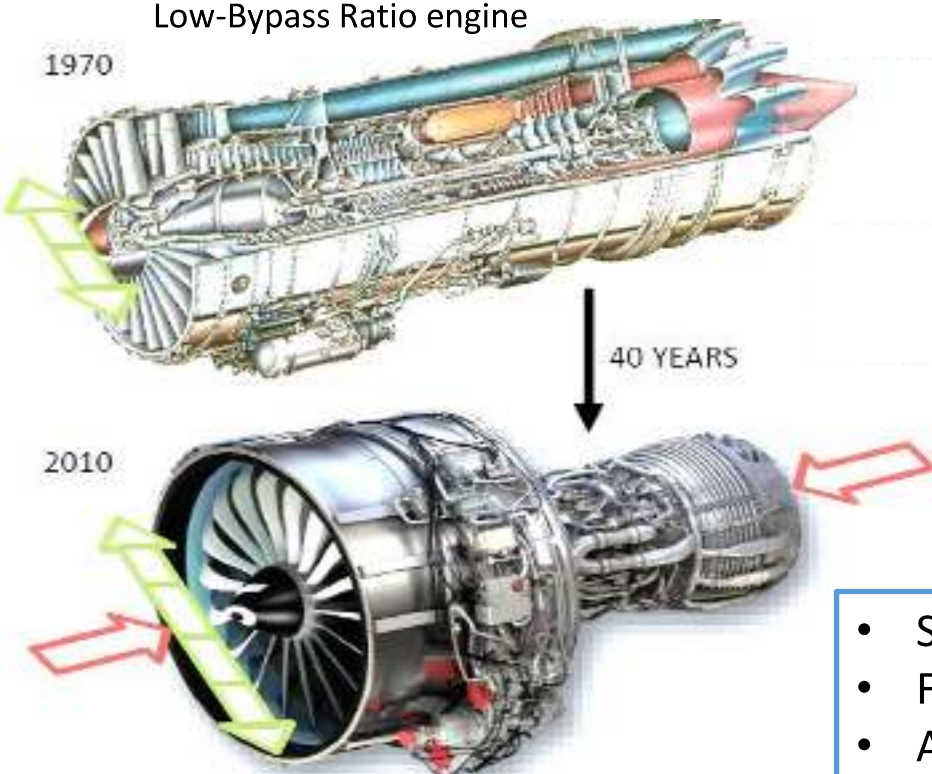
Modelling of passive damping



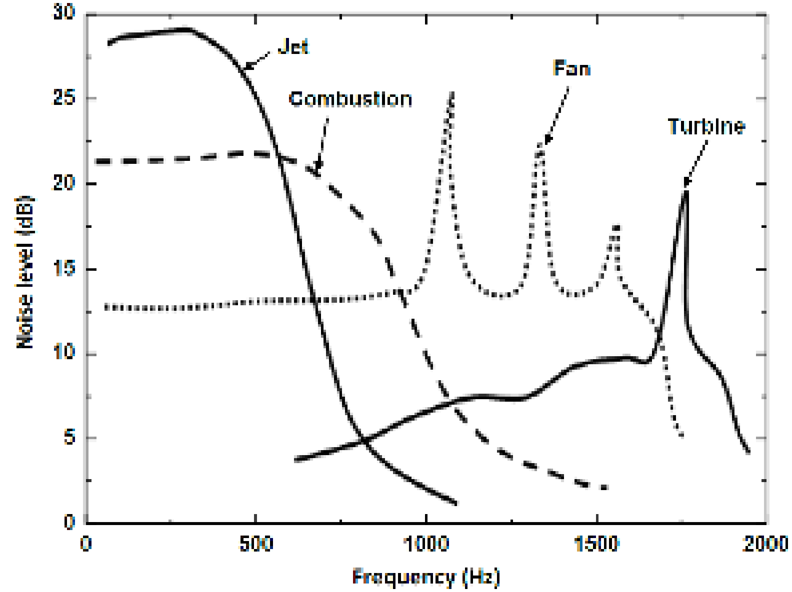
Engine noise

Motivations

Low-Bypass Ratio engine



High-Bypass Ratio engine

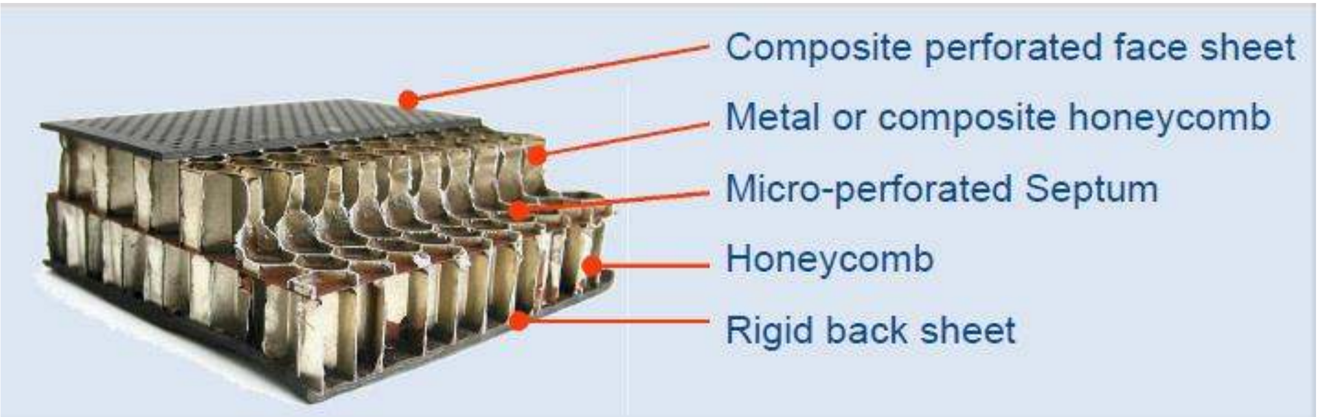


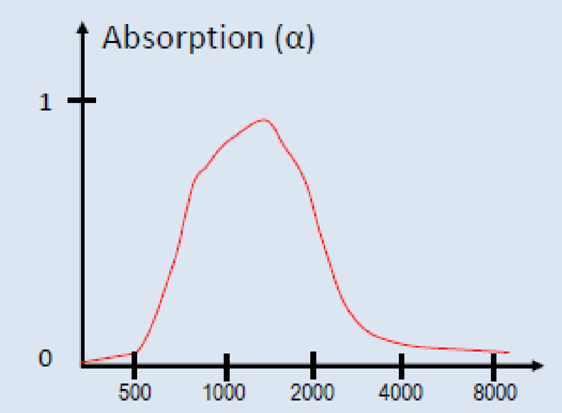
- Several sources of noise
- Fan noise important during take-off and landing
- Annoyance to communities around airports
- Discomfort for passengers
- Reduced durability of the structures

- Engine length reduced
- Nacelle diameter increased
- Areas for acoustic treatment narrowed

Engine noise

Locally reacting acoustic liner (Helmholtz resonators)



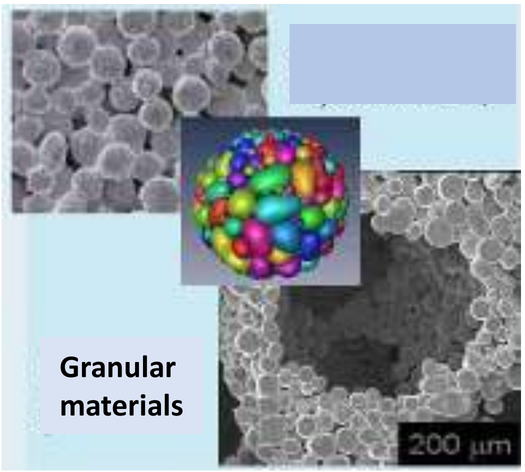


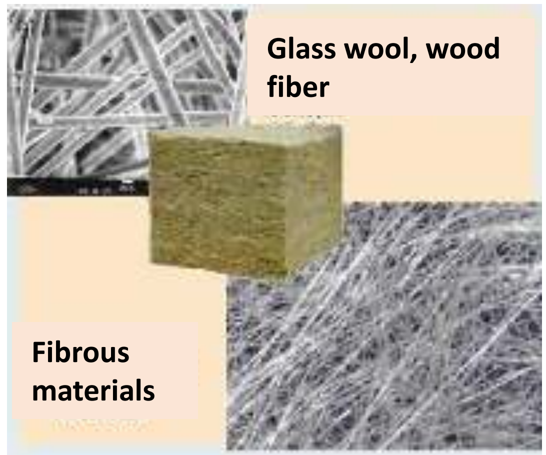
- Target only one octave band centered on fan blade passage frequencies
- Not suitable for critical areas such as OGVs
- Too cumbersome and heavy
- Development possibilities exhausted

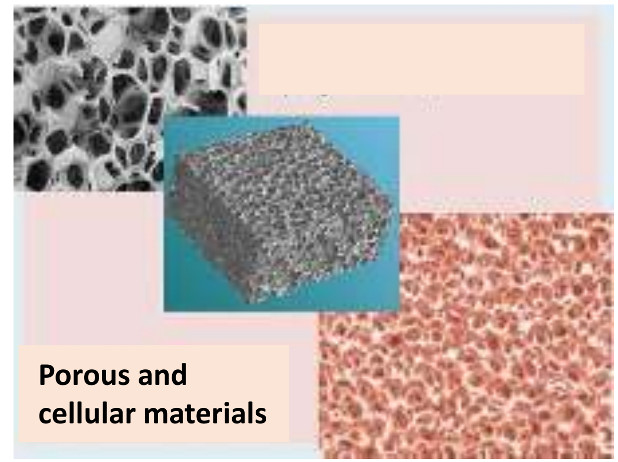
- Need for new technologies breakthrough
- Development of new absorbing materials
- Development of new acoustic concepts
- Development of new integration procedures

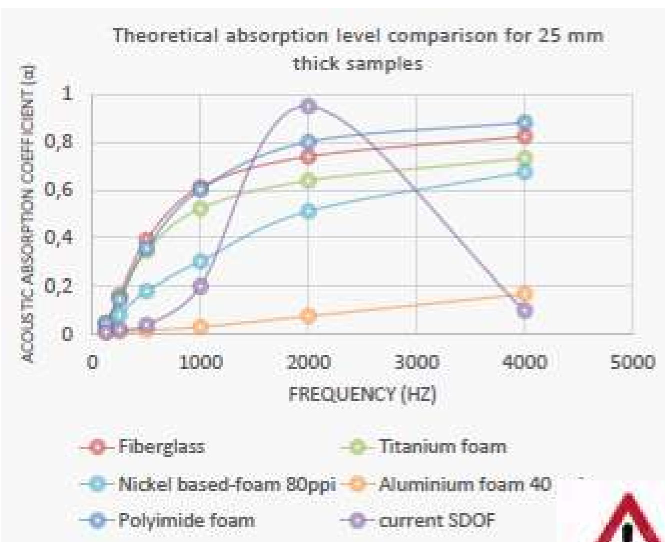
Absorbing materials

Non-locally reacting acoustic treatment









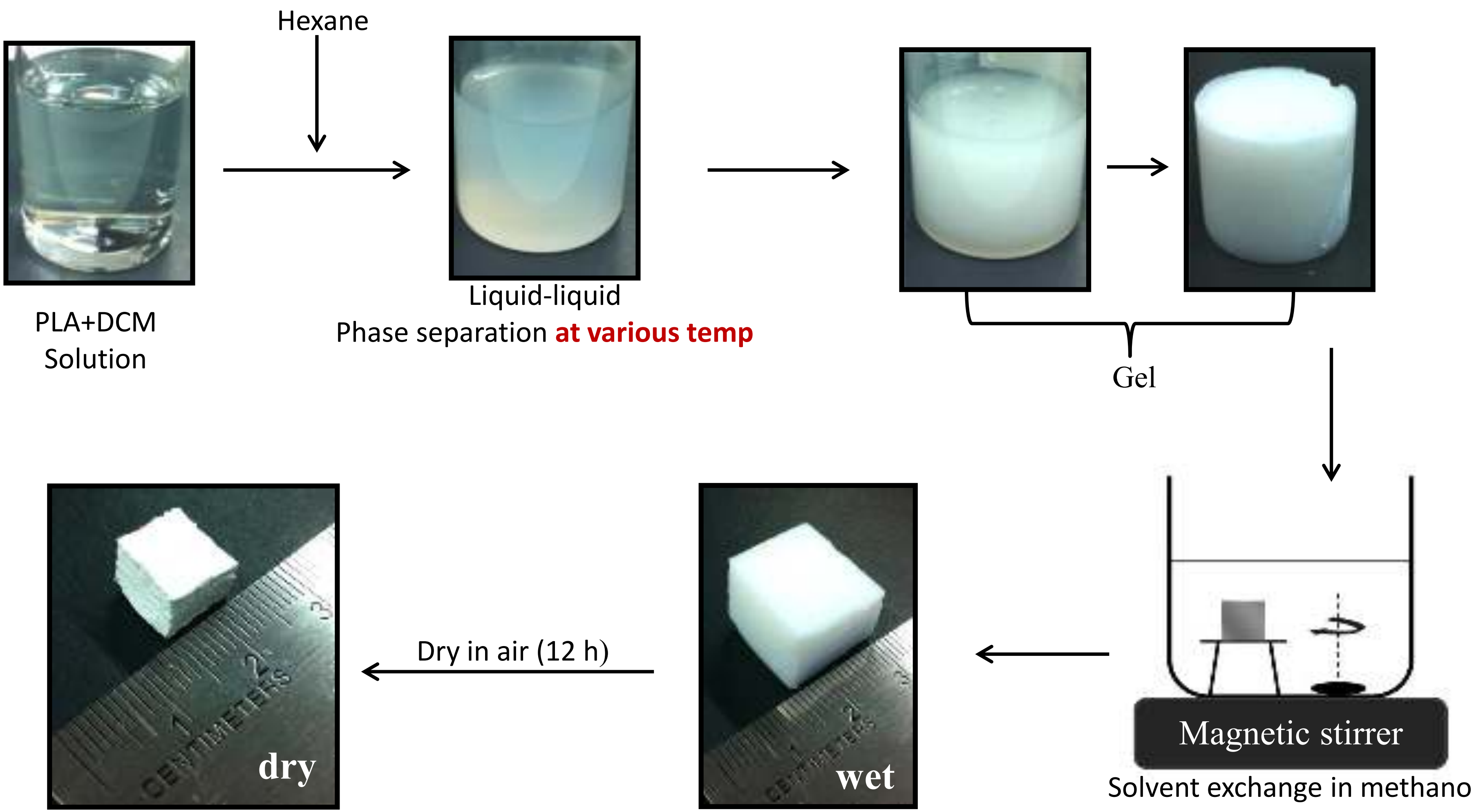
- High porosity metallic/carbon foams available
- Dissipation phenomena involved
- Broadband absorption frequency range
- Integration in composite environment

- Foaming processes difficult to control
- Foaming process expensive
- Mechanical behavior for high performance applications
- Ensuring long-term acoustic performance
- Certification compatibility

Absorbing materials

Foaming process PLA foams

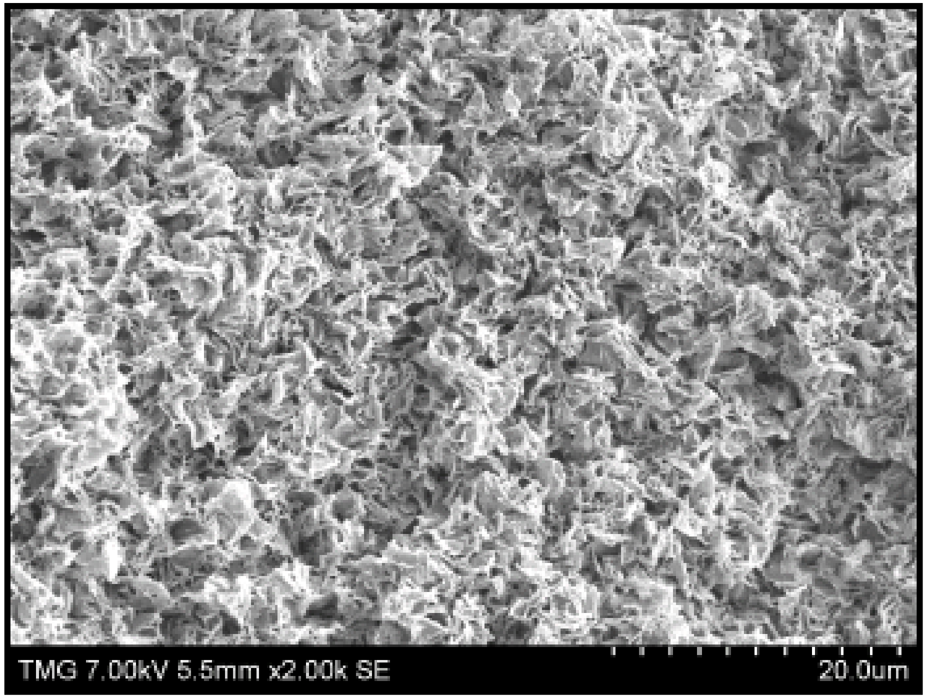
Non Solvent Induced Phase Separation (NIPS)



Absorbing materials

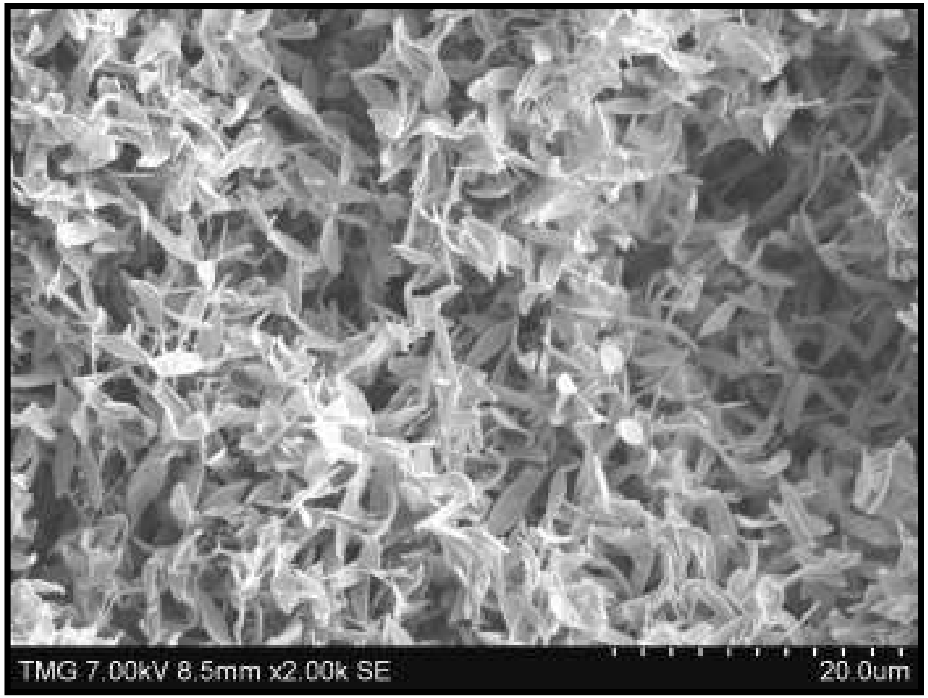
Microstructure PLA foams: Bimodal porosity

13 wt.% @ room temperature



Porosity = 45%
Compressive Strength = 45 MPa

23 wt.% @ room temperature



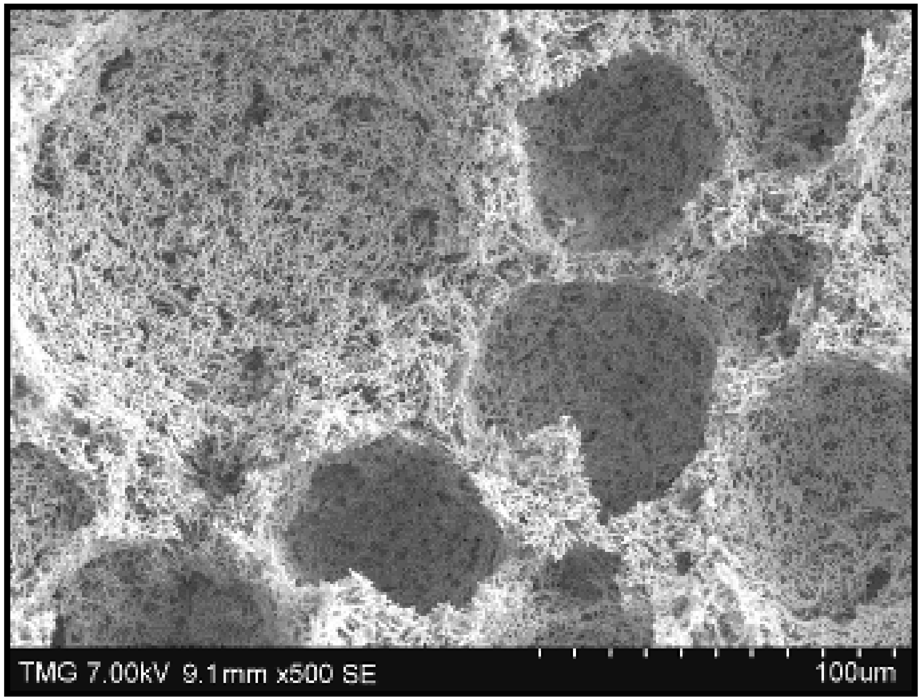
Porosity = 84%
Compressive Strength = 8 MPa

Rezabeigi et al, Production of PLA monoliths via NIPS , Polymer (55), 2014, 643-652

Absorbing materials

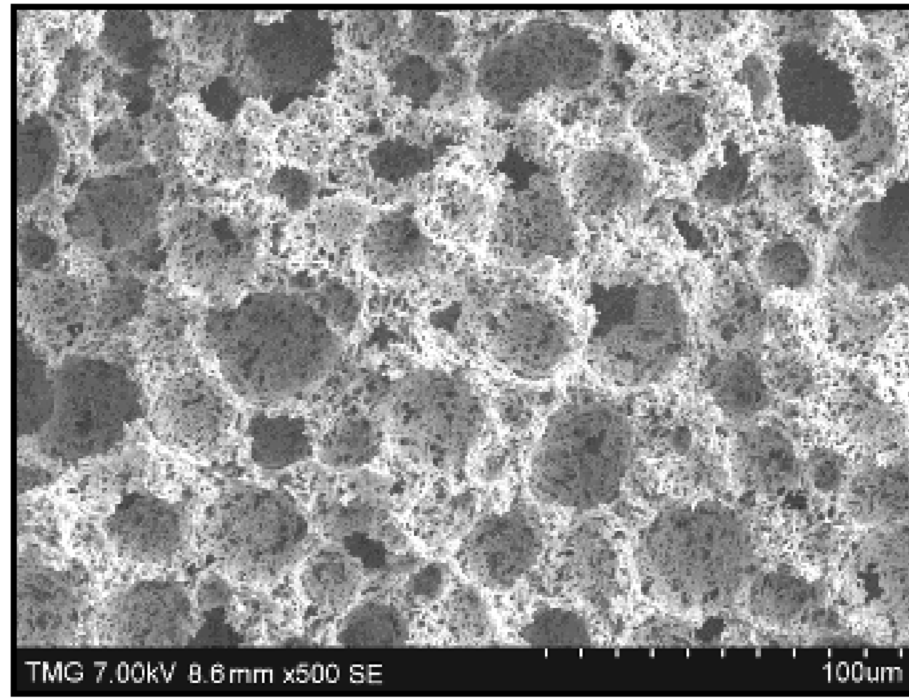
Microstructure PLA foams: Bimodal porosity

13 wt.% @ Freezer



Porosity = 91%
Compressive Strength = 1.8 MPa

23 wt.% @ Freezer



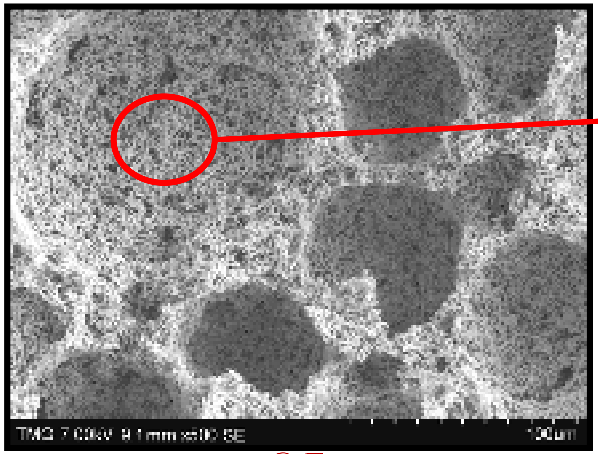
Porosity = 84%
Compressive Strength = 15.6 MPa

Nucleation & growth mechanism

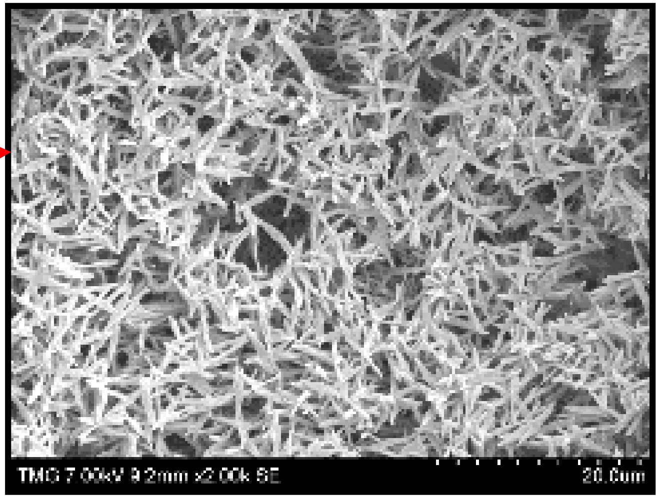
Rezabeigi et al, Production of PLA monoliths via NIPS , Polymer (55), 2014, 643-652

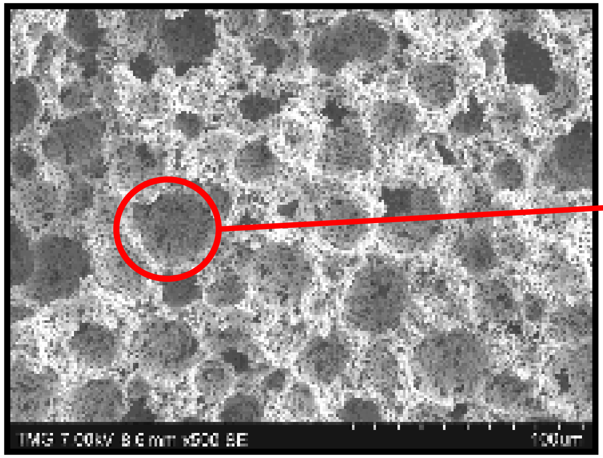
Absorbing materials

Microstructure PLA foams: Bimodal porosity

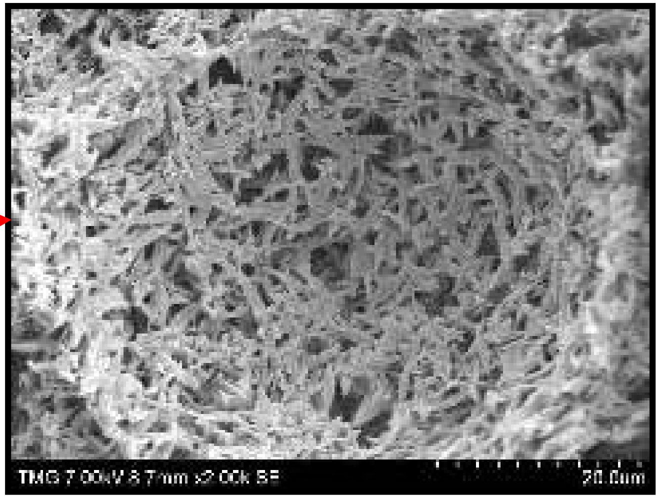


13 wt.% @ Freezer





23 wt.% @ Freezer

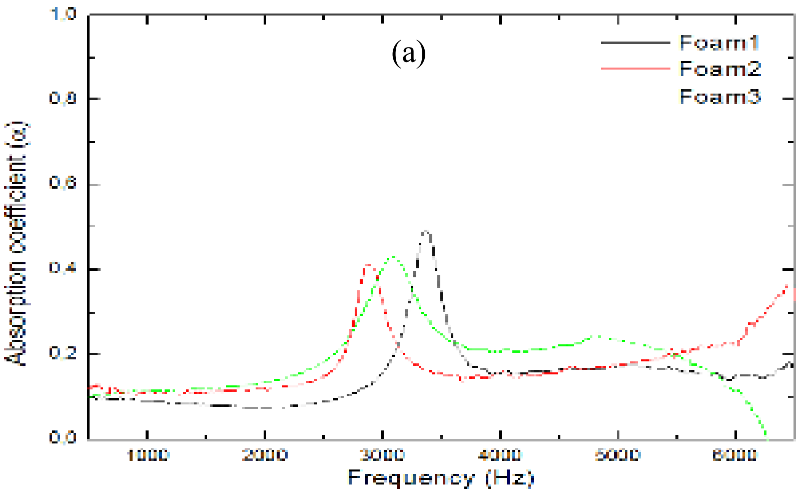


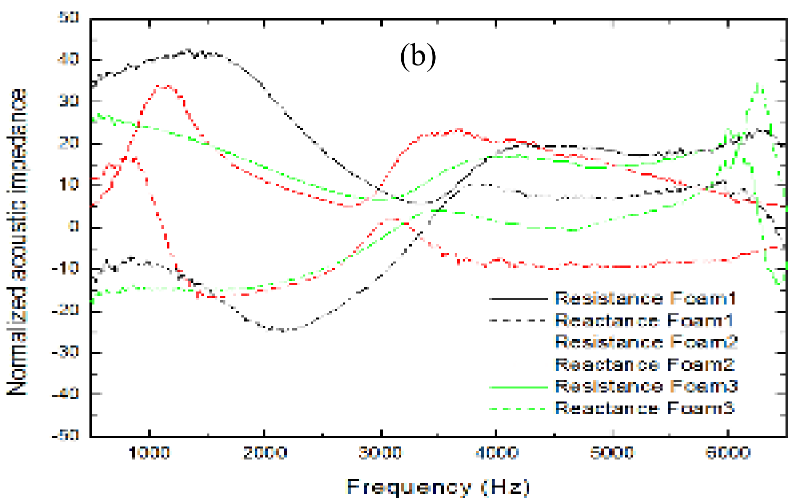
Crystallization of PLA

Rezabeigi et al, Production of PLA monoliths via NIPS , Polymer (55), 2014, 643-652

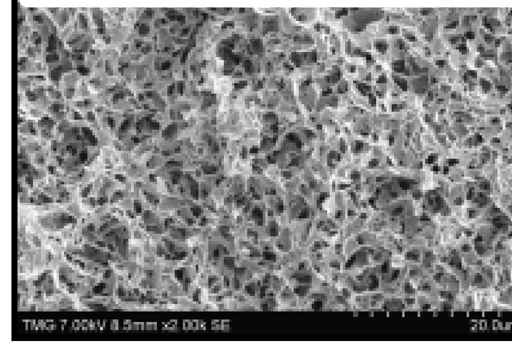
Absorbing materials

PLA foams



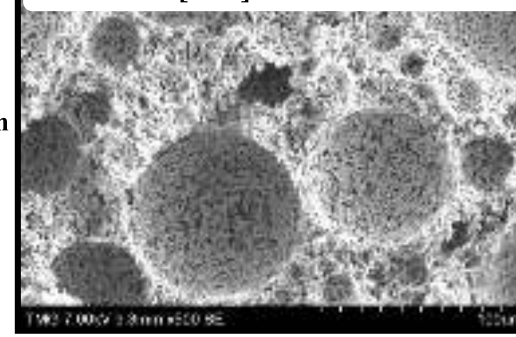


Foam1 : [L-L] 18 wt.% @ 23°C



Thickness:
Porosity: 88%
Average pore size: 10.3 nm
Comp. modulus: 14 MPa
Density: 0.14g/cm3

Foam2: [S-L] 13 wt.% @ 23°C



Thickness:
Porosity: 86%
Average pore size: 15.4 nm
Comp. modulus: 3.5 MPa
Density: 0.17g/cm3

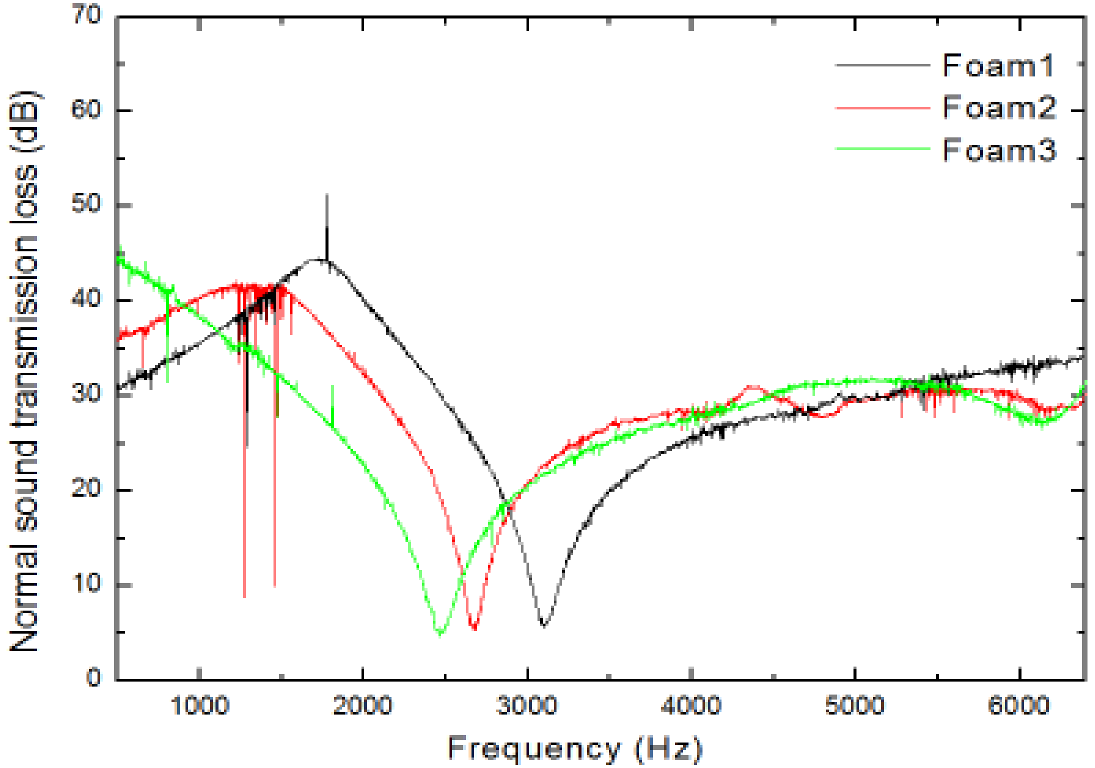
Foam3: [L-L] 18 wt.% @ - 23°C

Thickness:
Porosity: 91%
Average pore size: 12.7 nm
Comp. modulus: 1,8 MPa
Density: 0.12g/cm3

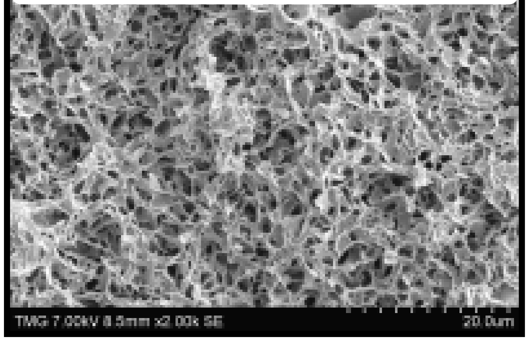
Resonance-like acoustic absorption (3000Hz and 3500Hz)

Absorbing materials

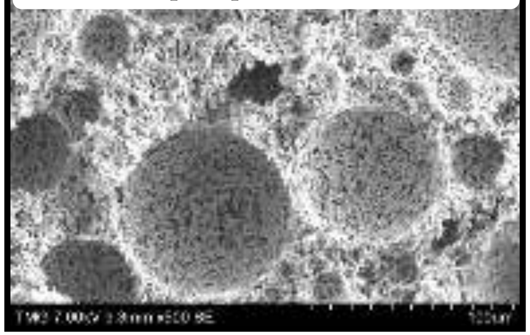
PLA foams



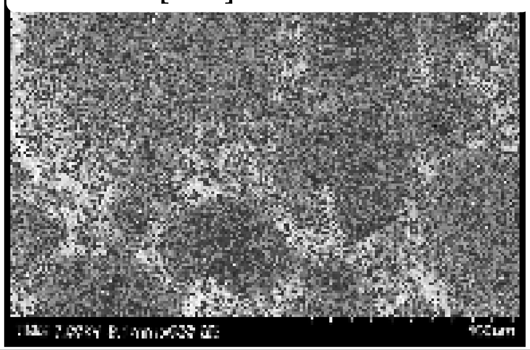
Foam1 : [L-L] 18 wt.% @ 23°C



Foam2: [S-L] 13 wt.% @ 23°C



Foam3: [L-L] 18 wt.% @ - 23°C



- Interesting transmission capabilities at low frequency
- Can be used as absorbing material and sound barrier

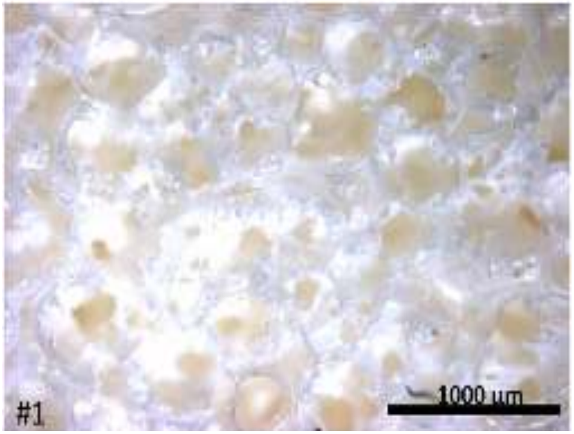
Fotsing et al, Acoustic properties of porous PLA monoliths produced via NIPS, ICTAM 2016 (Montreal)

Thermoset foams

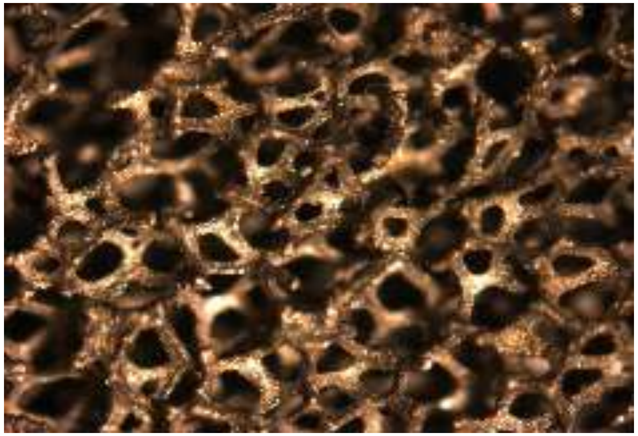
Innovative process to produce thermoset foams

- Simple and flexible
- Cost effective
- Fully controllable

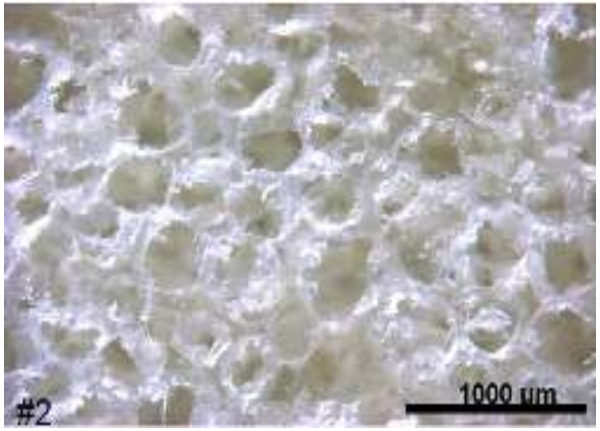
- Porosity greater than 85 % (ideal for acoustic treatment)
- Improved mechanical properties (up to 50 MPa compressive modulus)
- Porosity gradient through the thickness (ideal for non-locally acoustic treatment)
- Easy integration to composite structures (e.g. sandwich structures)



Foam #1



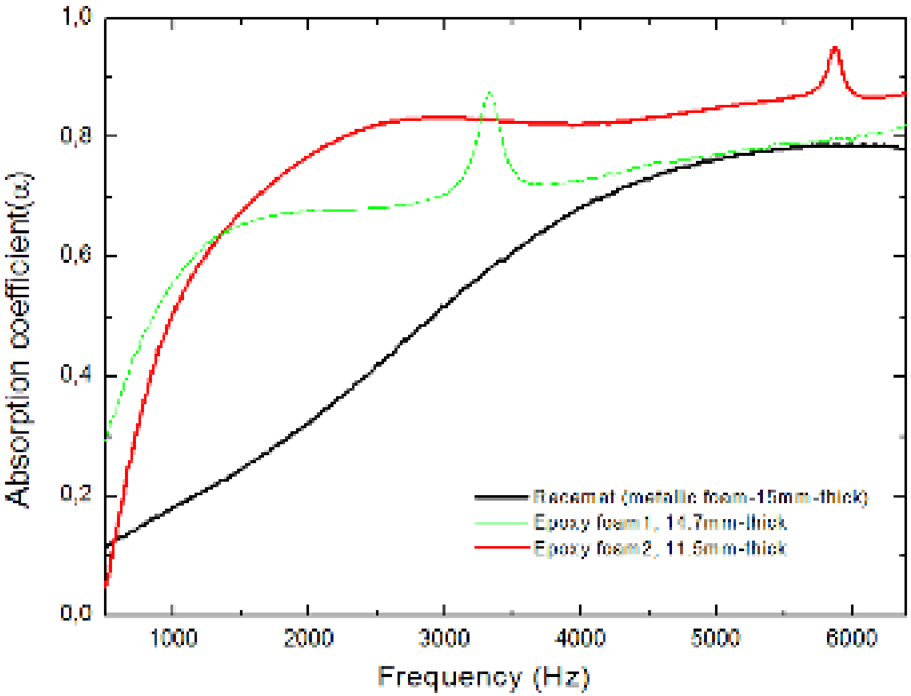
Commercial metallic foam (Recemat)

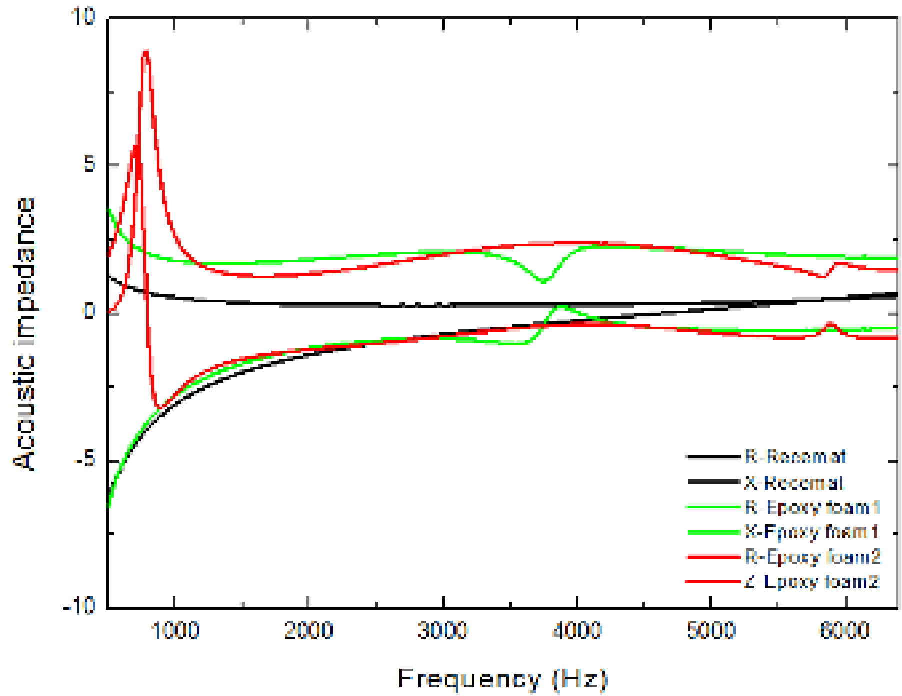


Foam #2

Absorbing materials

Thermoset foams





- Epoxy foam slightly more resistive than the metallic foam
- Absorption on a broad frequency range for epoxy foam

Absorbing materials

Characterization and modelling

Concept of equivalent fluid

$$\Delta p + \omega^2 \frac{\tilde{\rho}_{eq}}{\widetilde{K}_{eq}} p = 0$$

JCA model

$$\widetilde{\rho_{eq}} = \frac{\alpha_\infty \rho_0}{\phi}\left[1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty}\sqrt{1 + j\omega\frac{4\alpha_\infty^2\eta\rho_0}{\sigma^2\Lambda^2\phi^2}}\right]$$

$$\widetilde{K_{eq}} = \frac{\gamma P_0}{\phi}\frac{1}{\gamma - (\gamma-1)\left[1 - j\frac{8\kappa}{\Lambda'^2 C_p\rho_0\omega}\sqrt{1 + j\omega\frac{\Lambda'^2 C_p \rho_0}{16\kappa}}\right]^{-1}}$$

Characteristic impedance	$\widetilde{Z_c} = \sqrt{\widetilde{\rho_{eq}}\widetilde{K_{eq}}}$
Wave number	$\tilde{k} = \omega\sqrt{\frac{\widetilde{\rho_{eq}}}{\widetilde{K_{eq}}}}$
Normal surface impedance	$Z = -jZ_c \cot(\tilde{k}\, e)$
Absorption coefficient	$\alpha = 1 - \frac{\tilde{Z} - Z_0}{\tilde{Z} + Z_0}$

5 parameters to be characterized (ϕ, σ, α_∞, Λ, Λ')

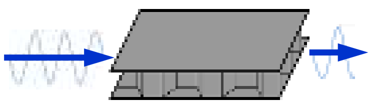
Direct method (experimental)

- Impedance tube (α, Z)
- Resistivity meter (σ)
- Porosity meter (ϕ)
- Tortuosity meter(α_∞ Λ Λ')

Inverse method

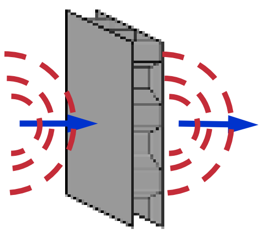
Comparing the model with experimental values of acoustic absorption and acoustic impedance

Conclusion



Implement mechanical damping solutions

- Lightweight
- Non intrusive
- High performance
- Cost effective



Implement sound barrier solutions

- Lightweight
- Non intrusive
- High performance
- Cost effective

Implement acoustic absorption solutions

- Lightweight
- Non intrusive
- High performance
- Cost effective

Implement functionalities

to

existing structures

at the

design stage

Innovative concepts

No corrective patches !

Thank you

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