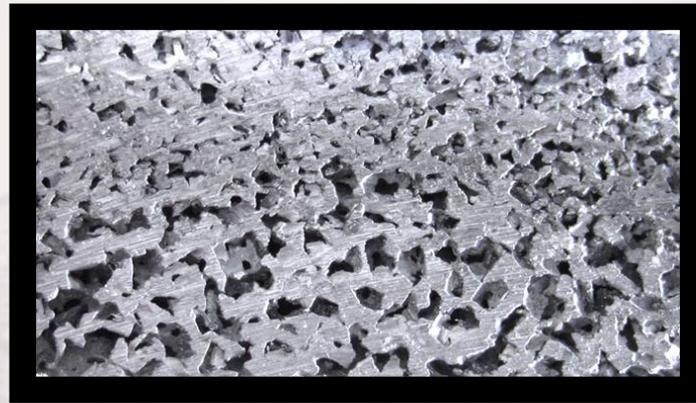


Impact test and mixture approach to the study of the acoustic properties of rigid frame porous materials with functionally graded macroscopic physical parameters

DRIVE,
Université de Bourgogne



C. Sacristán^a, T. Dupont^a, O. Sicot^a, P. Leclaire^a, K. Verdière^b, R. Panneton^b et X.-L. Gong^c

^aDRIVE, Université de Bourgogne

^bGAUS, Université de Sherbrooke

^cLASMIS de l'UTT

Outline

1. Introduction

2. Foam with continuous property gradient

2.A - Principle : discretization in homogenous porous layers

2.B - Model and validation on a compressed homogenous foam : TMM – JCA equivalent fluid and model for the macroscopic parameters

2.C – Model and validation for the compressed truncated conic sample

- TMM (series stack)
- P-TMM (series and parallel stack)

3. Bi-layer aluminum foam

3.A – Fabrication with gradient interface

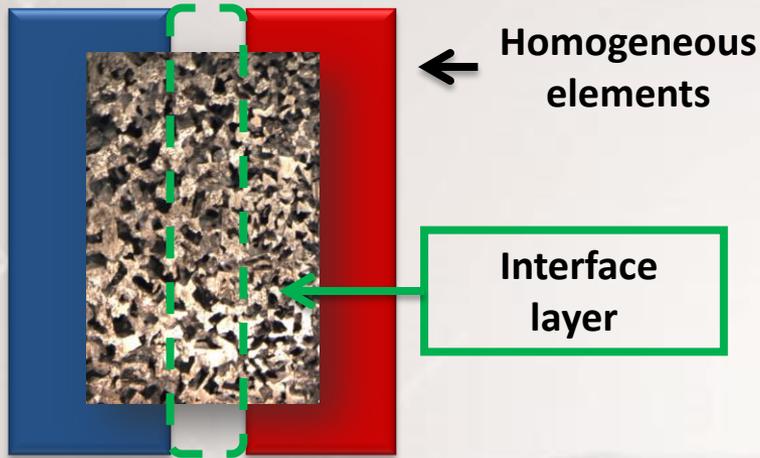
3.B - Model by P-TMM

4. Impact tests – absorption

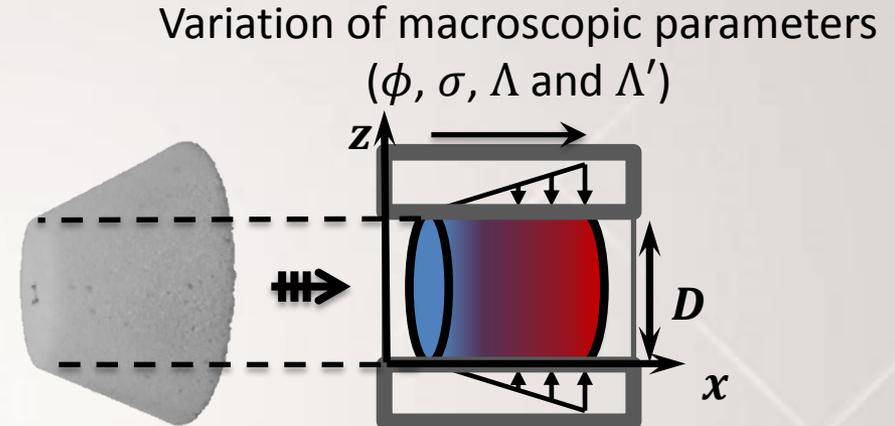
5. Conclusions

Issue : Inhomogeneous porous materials

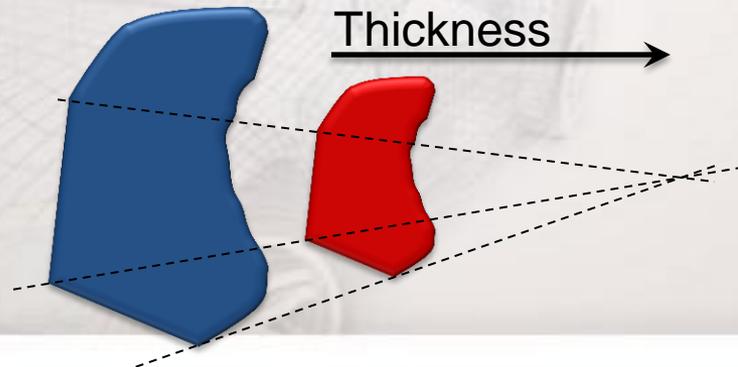
Bi-layer metallic foam



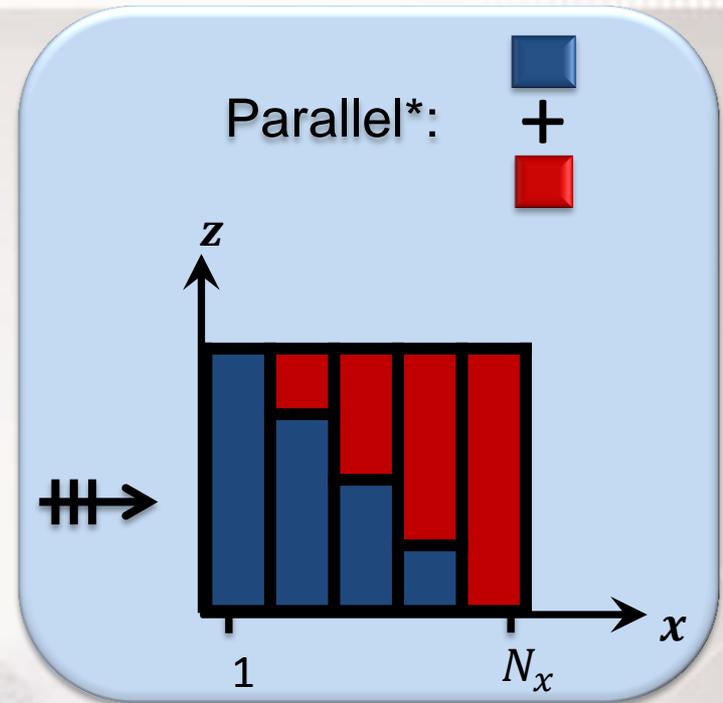
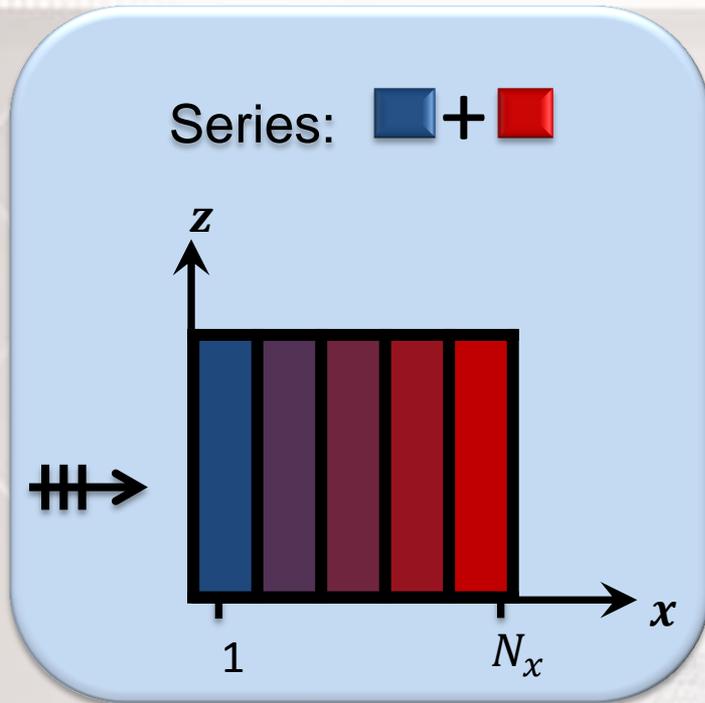
Conic melamine foam



Homothetic transformation



Issue : Inhomogeneous porous materials



Homogeneous element

Macroscopic JCA parameters

$\phi, \sigma, \alpha_{\infty}, \Lambda, \Lambda'$

JCA equivalent fluid model

Transfer matrix

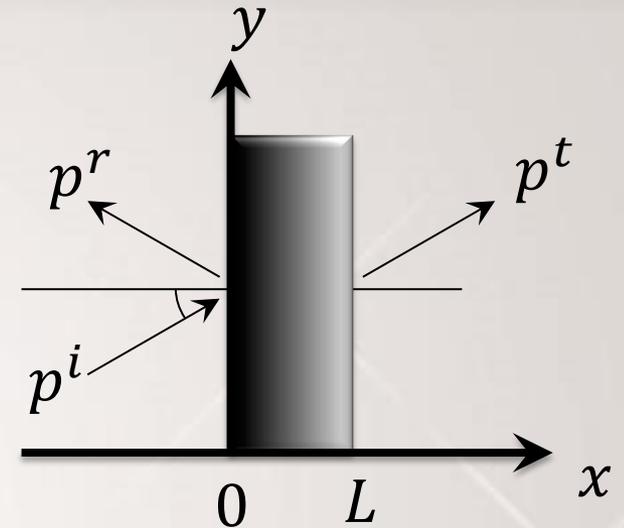
$[T_i]$

*K. Verdière et al. JASA, 134, (2013)

Introduction

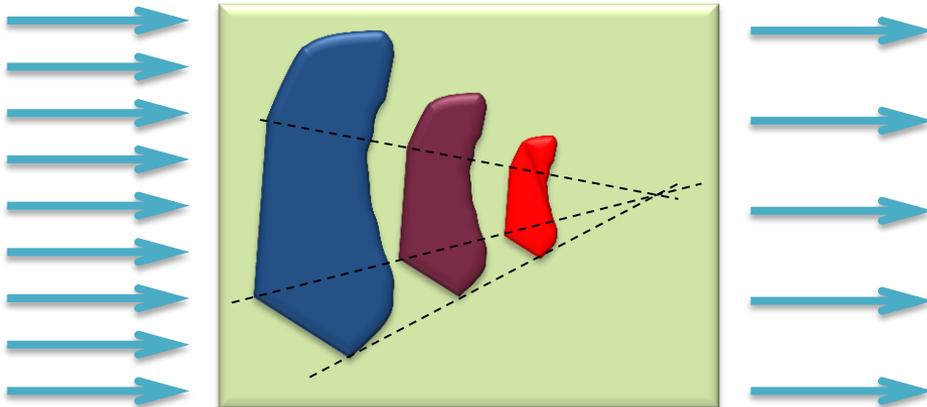
Variations of the macroscopic parameters

- L. De Ryck et al. APL, 90, (2007)
- L. De Ryck et al. JASA, 124, (2008)
- G. Gautier et al. JASA, 130, (2011)



Carman-Kozeny

[T. Bourbié et al. Editions Technip, (1986)]



$$\sigma, \Lambda \text{ et } \Lambda' \rightarrow \phi(x)$$

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- TMM (series stack)
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3. Bi-layer aluminum foam

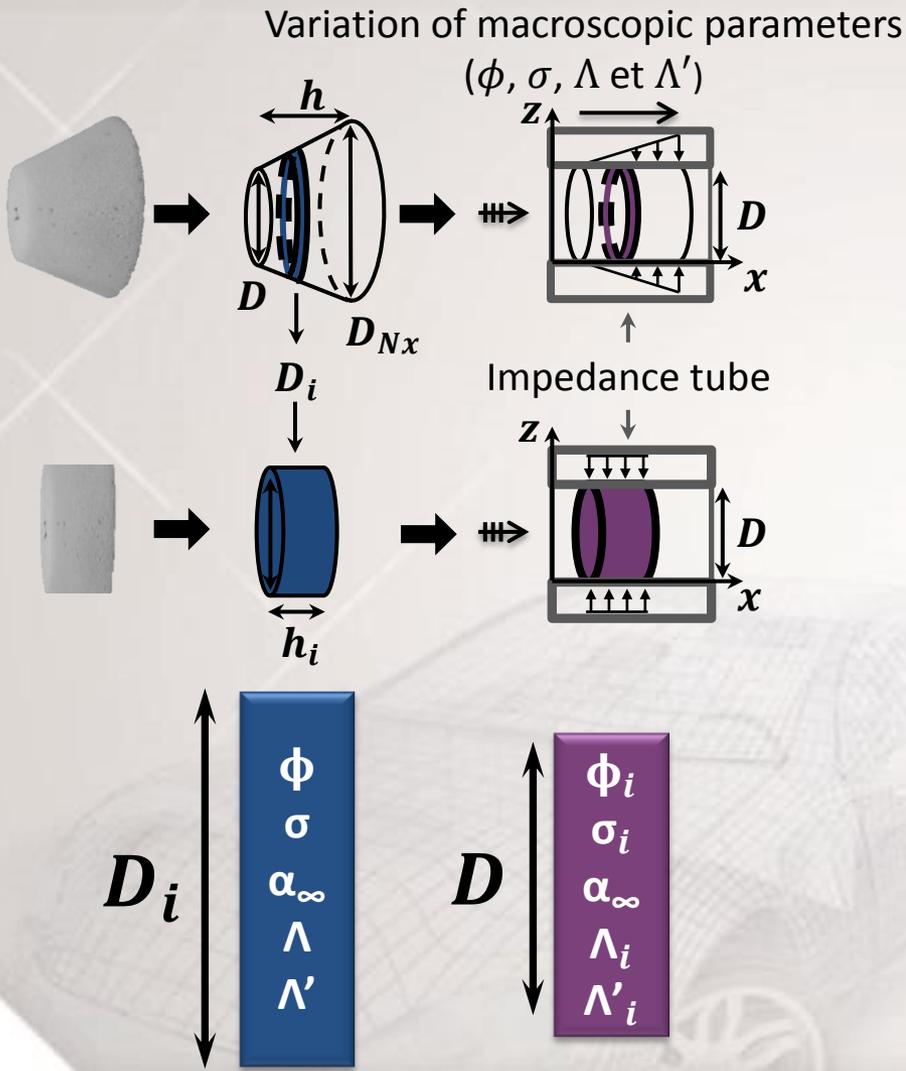
3.A – Fabrication with gradient interface

3.B - Model by P-TMM

4. Impact tests – absorption

5. Conclusions

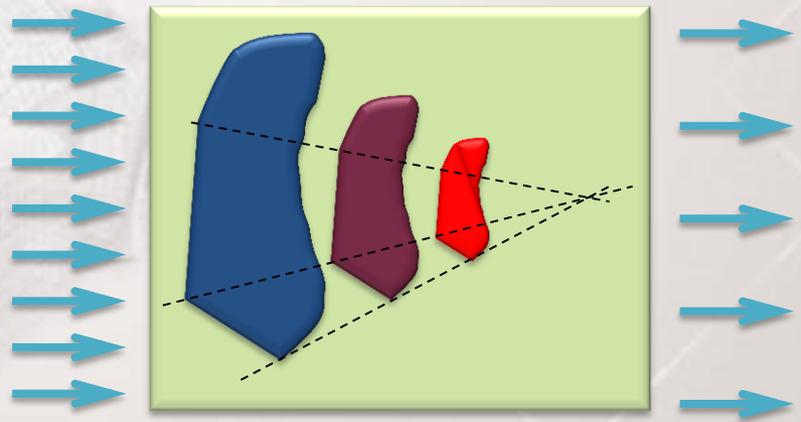
Foam with continuous property gradient: Principle : discretization in homogenous porous layers



Hypothesis :

Homothetic transformation

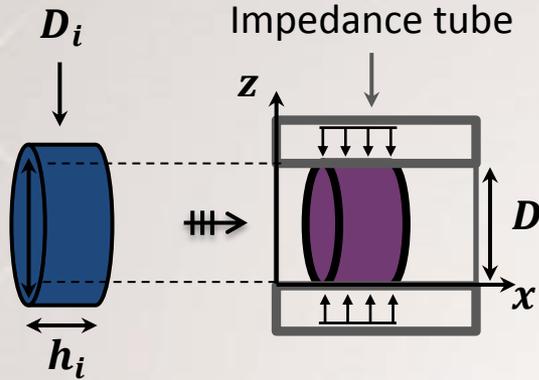
Carman-Kozeny



[T. Bourbiè et al. Editions Technip, (1986)]

Compressed homogeneous porous sample :

Model for the macroscopic parameters



Porosity

$$V_{solide} = Cst$$

[B. Castagnède et al.
Appl. Acoust., (2000)]

$$\phi_i = 1 - (1 - \phi) \left(\frac{D_i}{D}\right)^2$$

Density

$$\alpha_\infty = 1 + (\alpha_\infty - 1) \left(\frac{D_i}{D}\right)^2$$

[B. Castagnède et al.
Appl. Acoust., (2000)]

$$\rho_i = \left(\frac{1 - \phi_i}{1 - \phi}\right) (\rho - \phi \rho_{air}) + \phi_i \rho_{air}$$

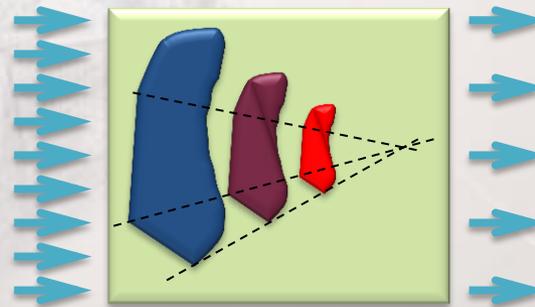
Homothetic transformation

Carman-Kozeny

[T. Bourbiè et al. Editions
Technip, (1986)]

$$\Lambda'_i = \left[\left(\frac{1 - \phi}{1 - \phi_i}\right) \left(\frac{\phi_i}{\phi}\right) \right]^{1/2} \Lambda'$$

$$\Lambda_i = \left[\left(\frac{1 - \phi}{1 - \phi_i}\right) \left(\frac{\phi_i}{\phi}\right) \right]^{1/2} \Lambda$$

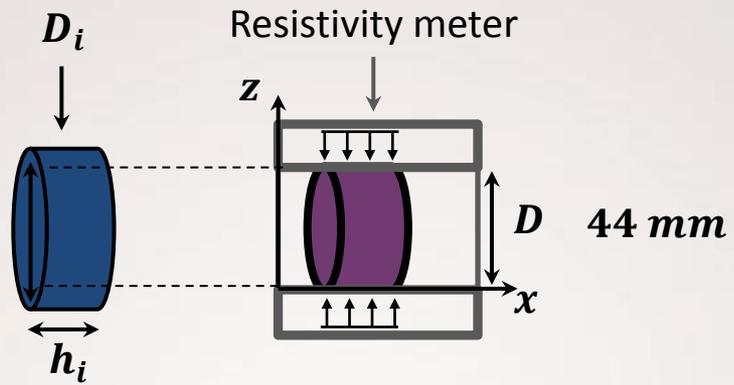


$$\kappa = \frac{A}{\alpha_\infty} R_H^2 \phi$$

$$\sigma_i = \left(\frac{1 - \phi_i}{1 - \phi}\right) \left(\frac{\phi}{\phi_i}\right) \sigma$$

Compressed homogeneous porous sample :

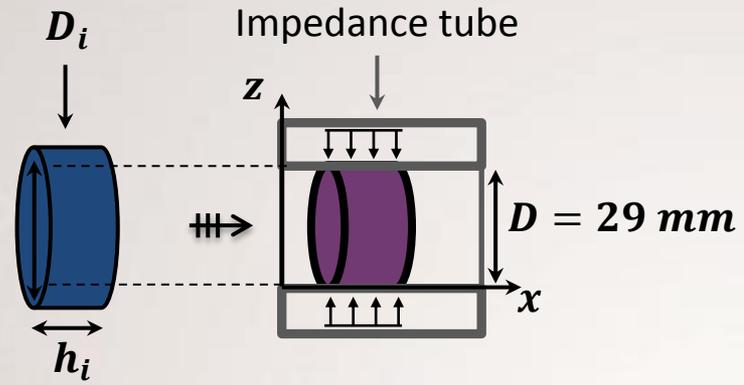
Validation



Flow resistivity validation		
D_i (mm)	48,6	58,3
h (mm)	24,4	24,1
σ_{The} ($\text{Pa} \cdot \text{s}/\text{m}^2$)	11727	17148
σ_{Exp} ($\text{Pa} \cdot \text{s}/\text{m}^2$)	13650	19034

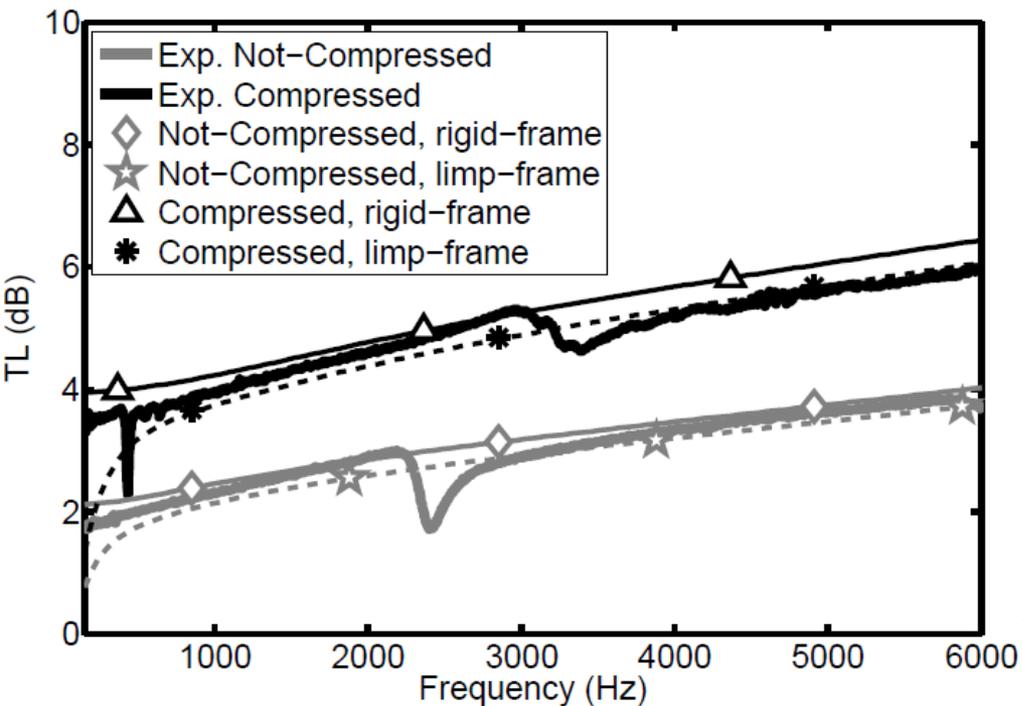
Compressed homogeneous porous sample :

Validation



	Not compressed (Measured)	Compressed (Model)
ϕ	0,99	0,97
$\sigma \text{ (Pa} \cdot \text{s/m}^2\text{)}$	11987	25091
α_∞	1,02	1,04
$\Lambda \text{ (}\mu\text{m)}$	80	56
$\Lambda' \text{ (}\mu\text{m)}$	138	96
$\rho \text{ (kg/m}^3\text{)}$	8	16
$h \text{ (mm)}$	23,3	14,3
$D \text{ (mm)}$	29	41,3

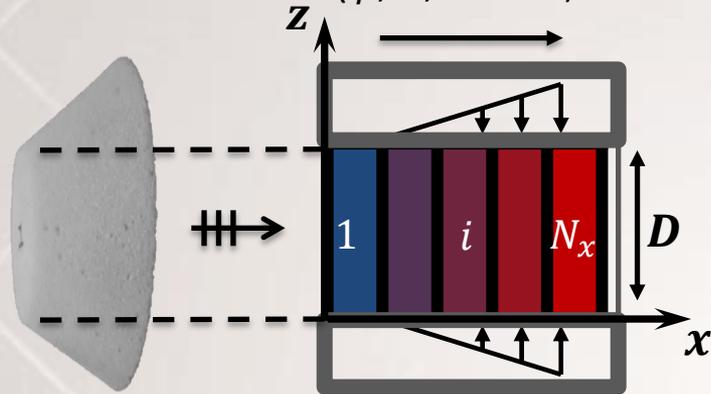
JCA parameters of a “compressed” melamine foam.



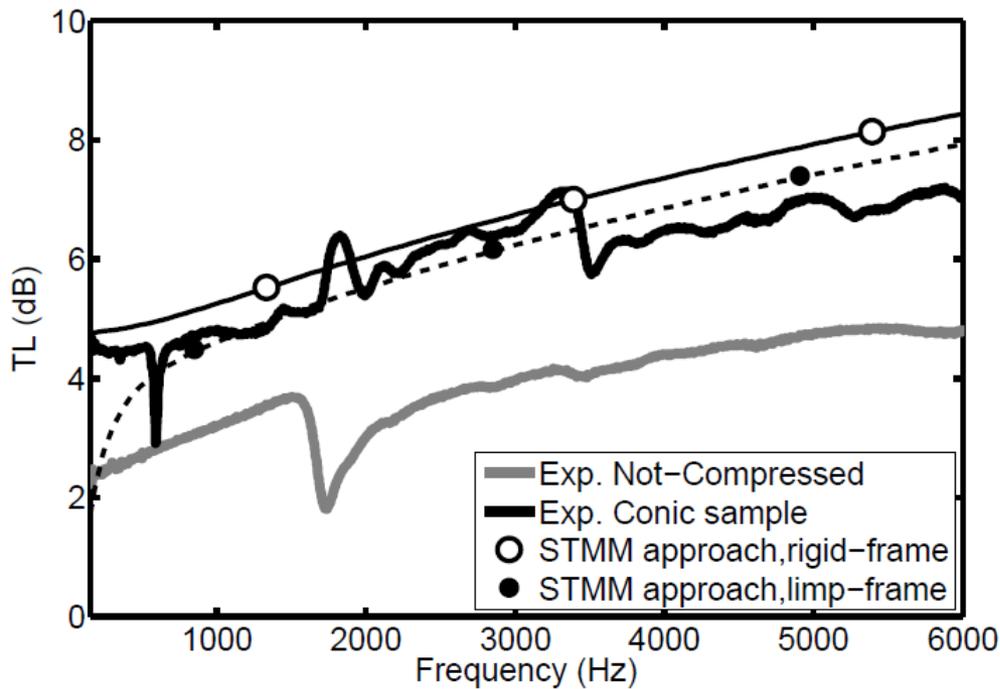
Model for the compressed truncated conic sample :

1 – Transfer Matrix Method with elements stacked in series

Variation of macroscopic parameters
(ϕ , σ , Λ et Λ')



	Not compressed (Measured)	Layer 1	Layer N_x
ϕ	0,99	0,98	0,96
σ ($Pa \cdot s/m^2$)	11987	12679	34855
α_∞	1,02	1,02	1,05
Λ (μm)	80	78	48
Λ' (μm)	138	134	82
ρ (kg/m^3)	8	9	21



Series stack :
Series TMM approach

 + 

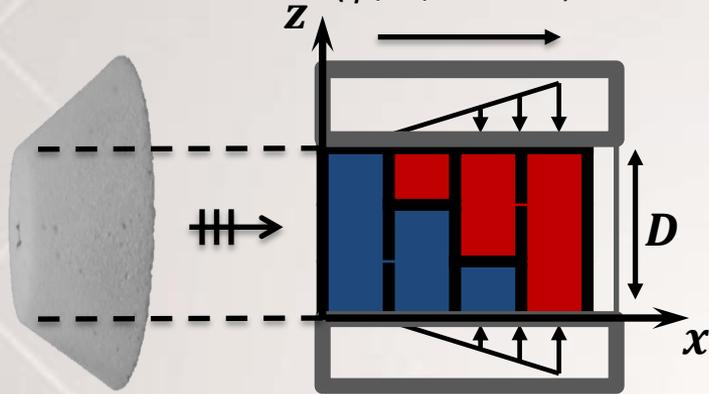
$$[T] = \prod_i^{N_x} [T_i]$$

Model of a compressed truncated conical foam :

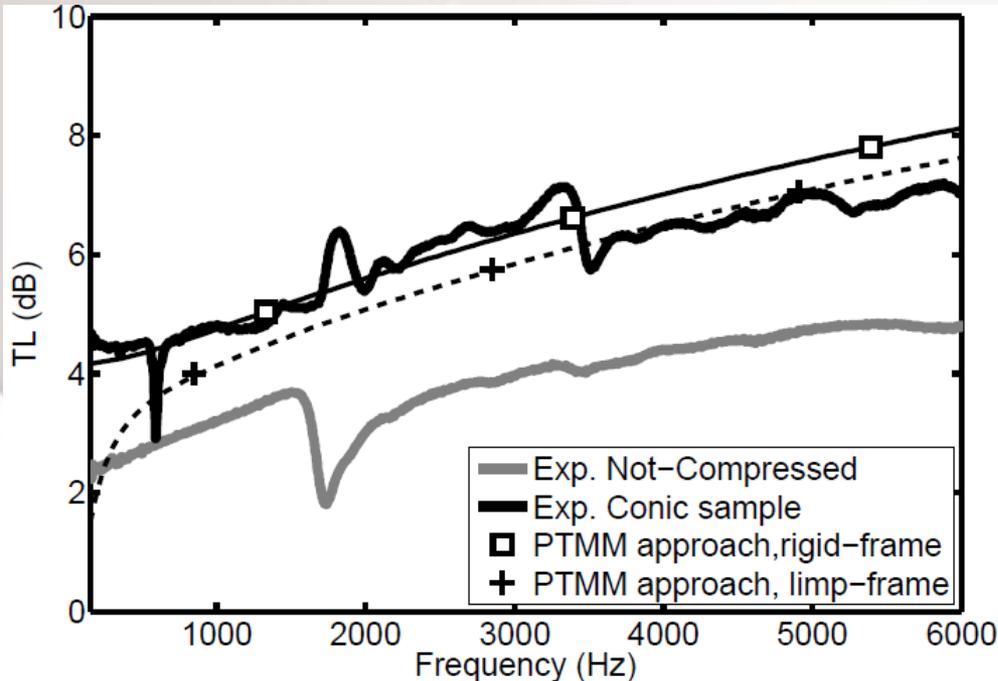
2 - Transfer Matrix Method with parallel elements - P-TMM

Variation of macroscopic parameters

$(\phi, \sigma, \Lambda$ et $\Lambda')$



	Not compressed (Measured)	Layer 1	Layer N_x
ϕ	0,99	0,98	0,96
σ ($Pa \cdot s/m^2$)	11987	12679	34855
α_∞	1,02	1,02	1,05
Λ (μm)	80	78	48
Λ' (μm)	138	134	82
ρ (kg/m^3)	8	9	21



Parallel stack :
Parallel TMM approach

K. Verdière et al.
JASA, 134, (2013)



$$[Y] = \prod_j^{N_y} [r_j [Y_j]]$$

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3. **Bi-layer aluminum foam**

3.A – Fabrication with gradient interface

3.B - Model by P-TMM

4. Impact tests – absorption

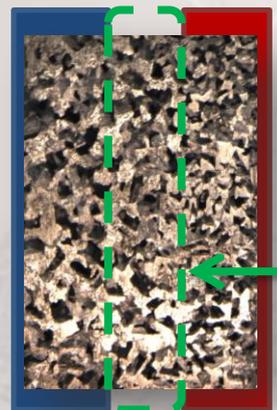
5. Conclusions

Aluminum foam :

Fabrication of bi-layer with gradient interface



Bi-layer aluminum foam



Interface layer

Homogeneous element

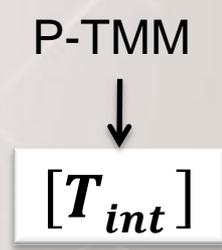
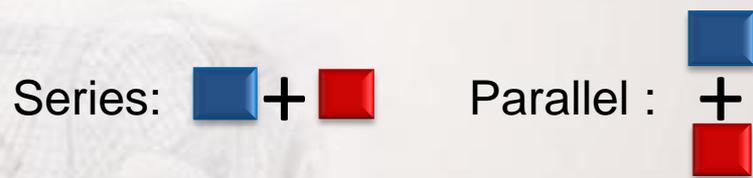
Foam \equiv 3 layers

$$[T] = [T_{mat1}][T_{int}][T_{mat2}]$$

1) Homogeneous elements

JCA equivalent fluide + TMM \rightarrow $[T_{mat, i}]$

2) Interface layer



Validation of approach / Metalique bi-layer foam

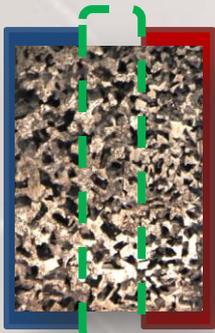
Pore size
1

+

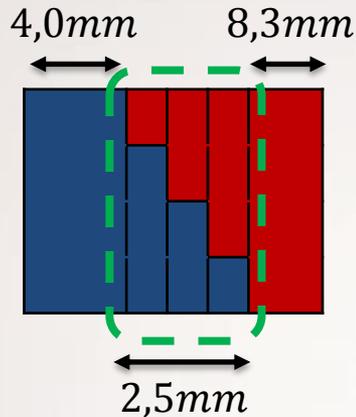
Interfaces
layers

+

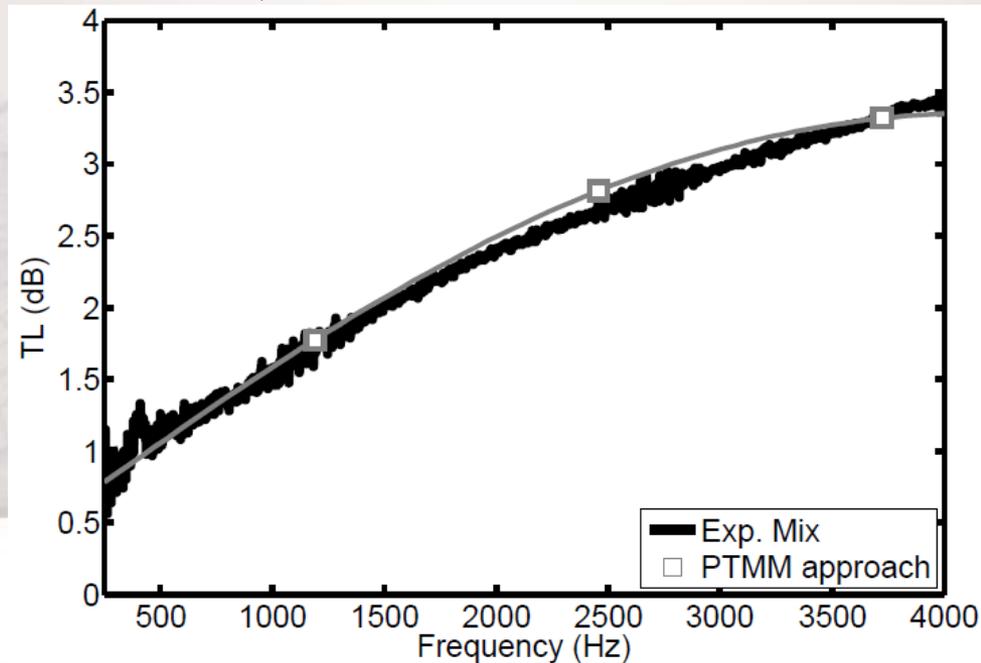
Pore size
2



14,8mm



	MF1	MF2
ϕ	0,64	0,66
σ ($Pa \cdot s/m^2$)	4316	3190
α_∞	1,6	1,7
Λ (μm)	170	223
Λ' (μm)	196	544
h (mm)	14,9	14,4



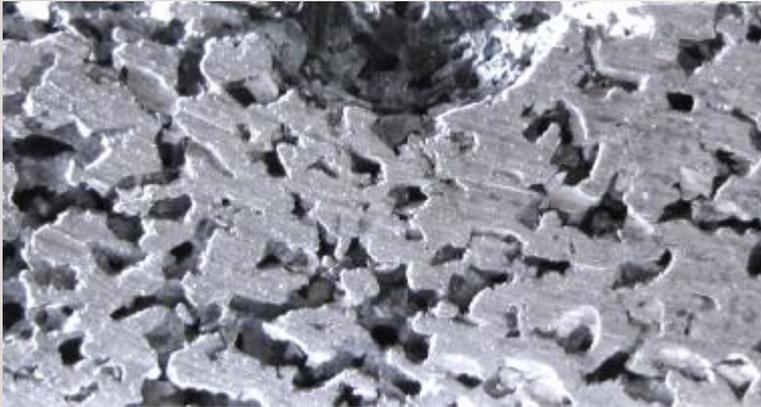
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 - 3.B - Model by P-TMM
- 4. Impact tests – absorption**
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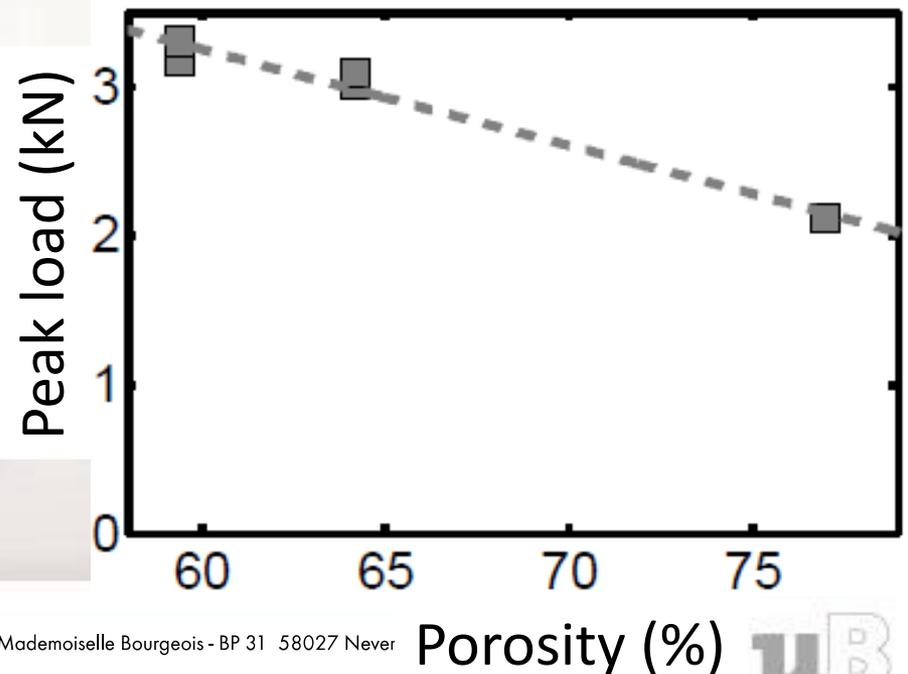
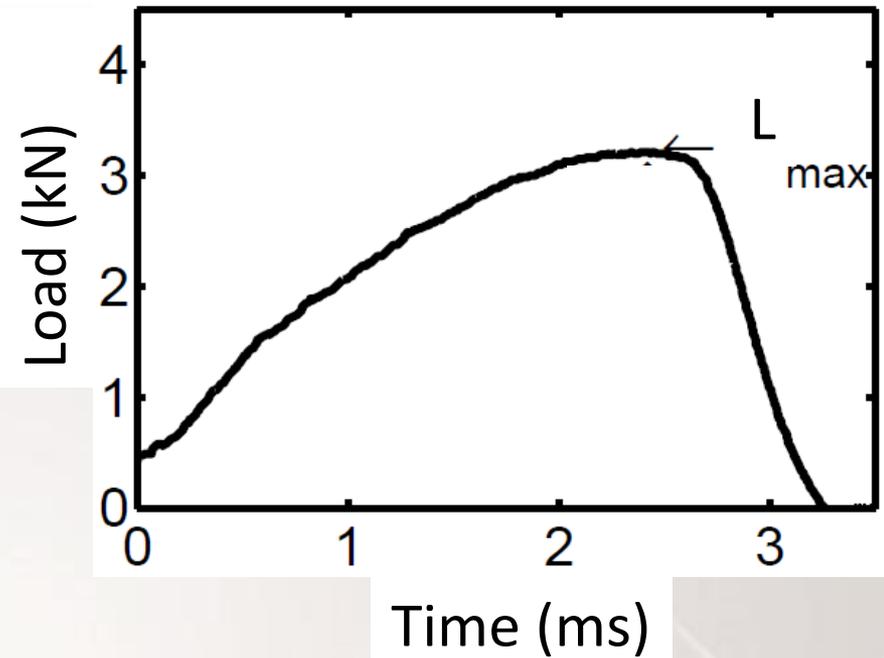
Impact test - absorption :

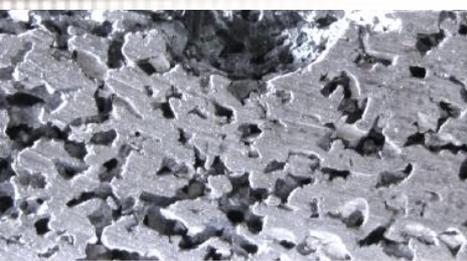
Energy impact : 4,1 J

Thickness : 15 mm

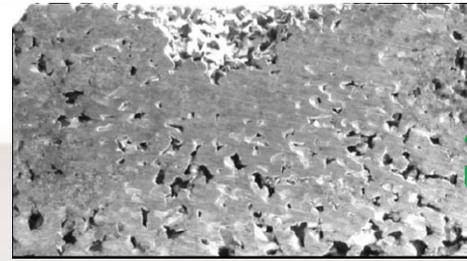


Cell size : 1,6 mm

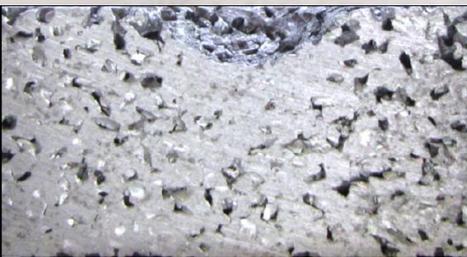
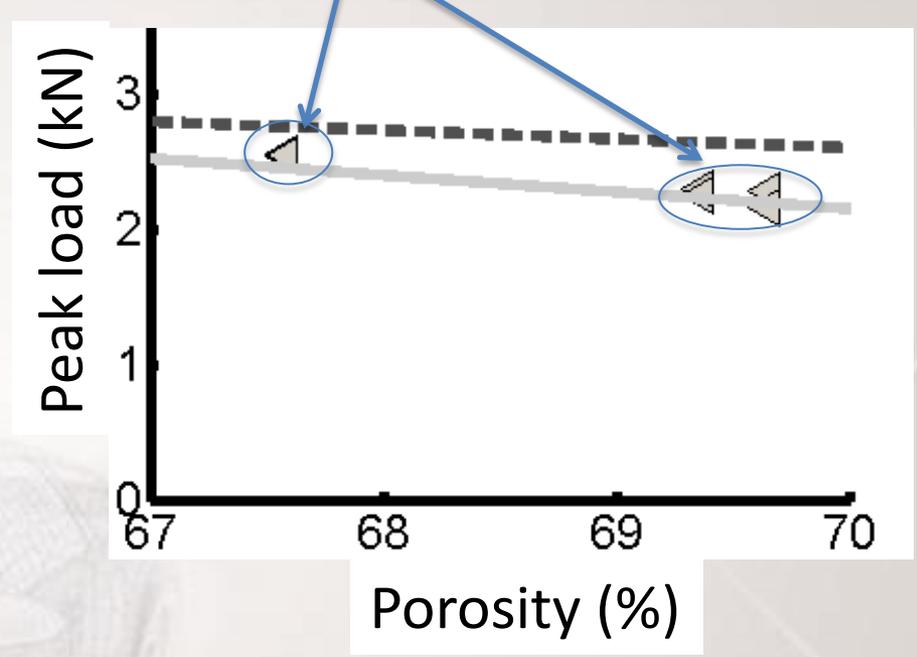
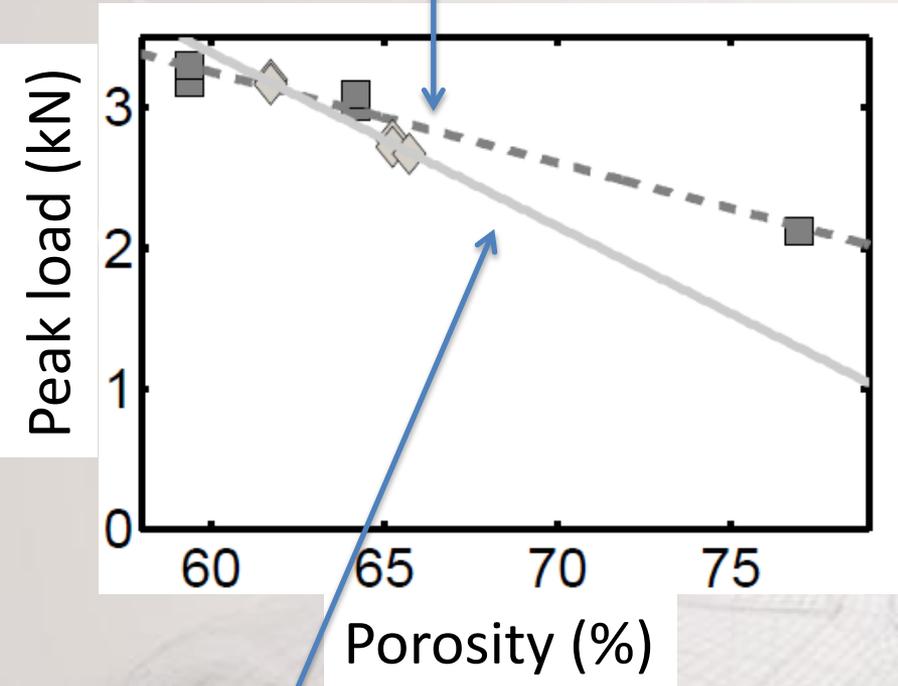




Cell size : 1,6 mm

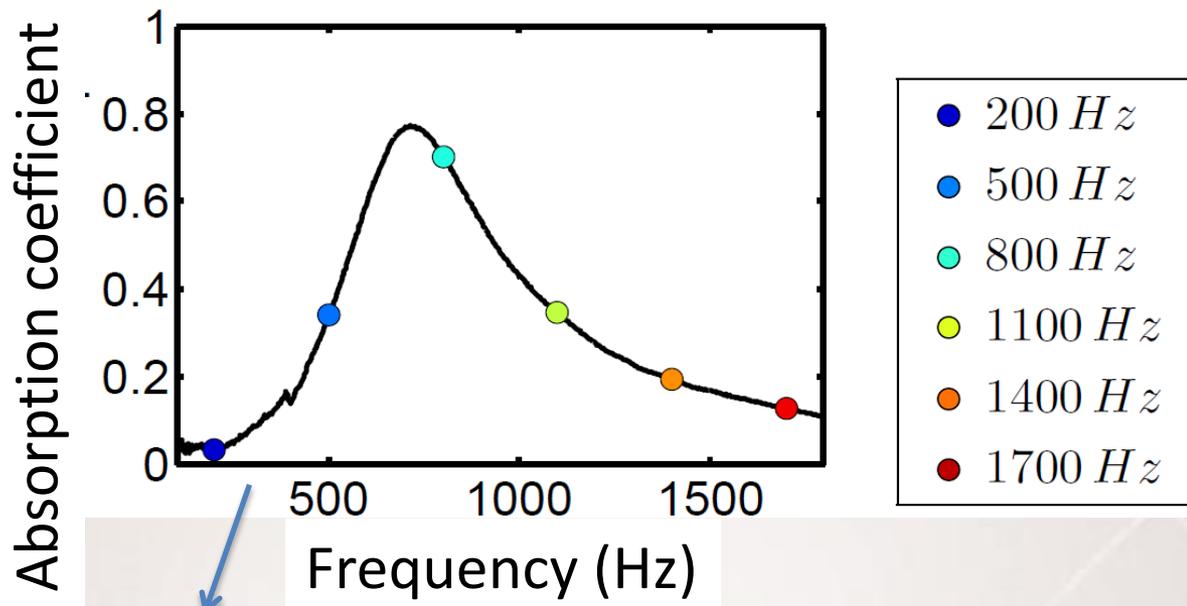


Cell size : 1,0 mm
Cell size : 1,6 mm

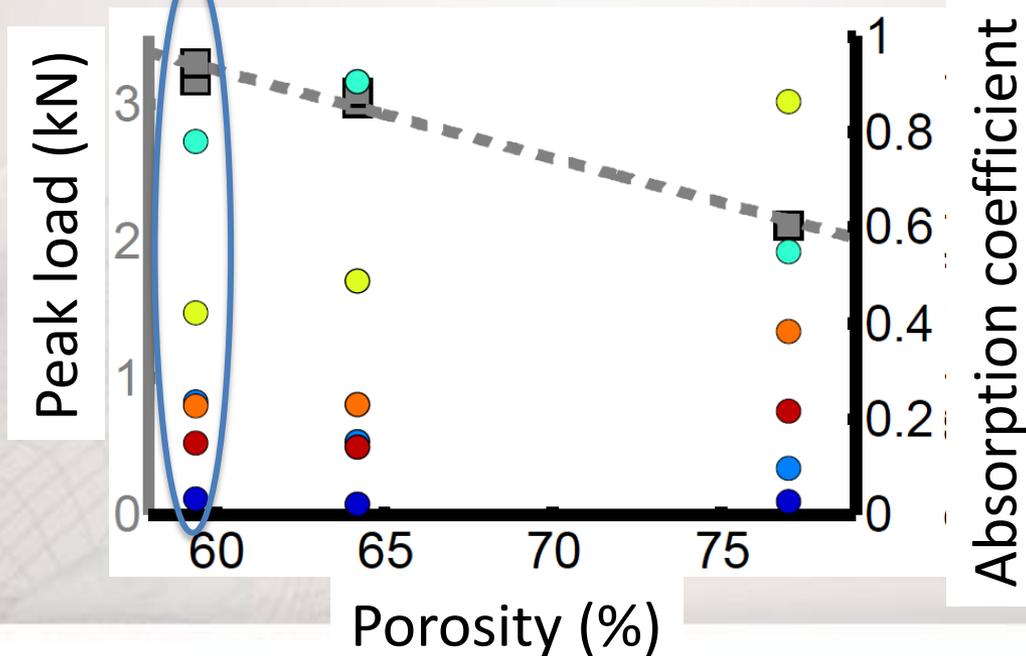


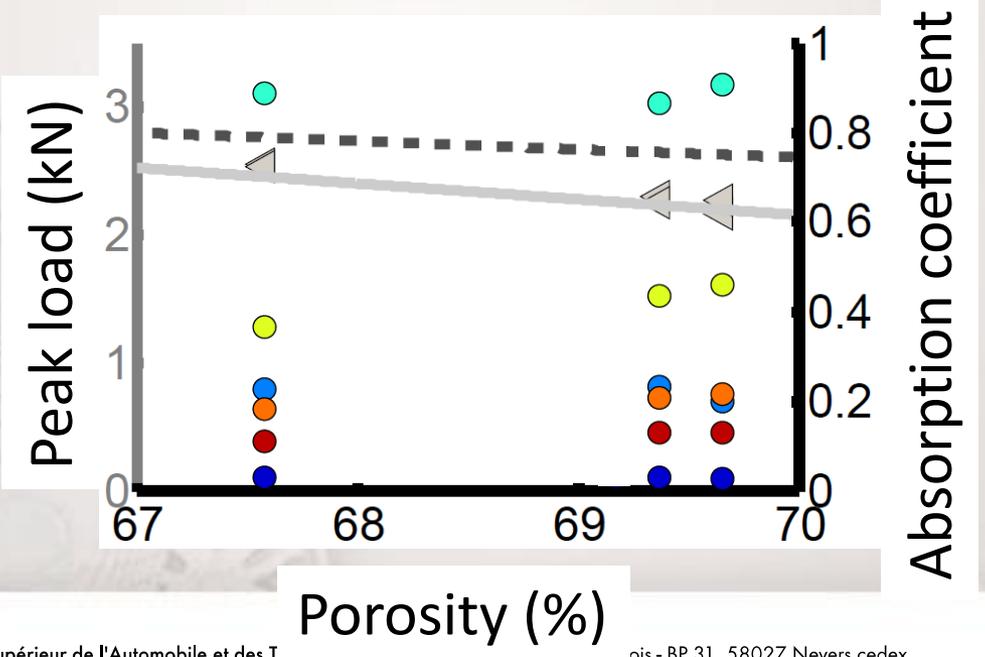
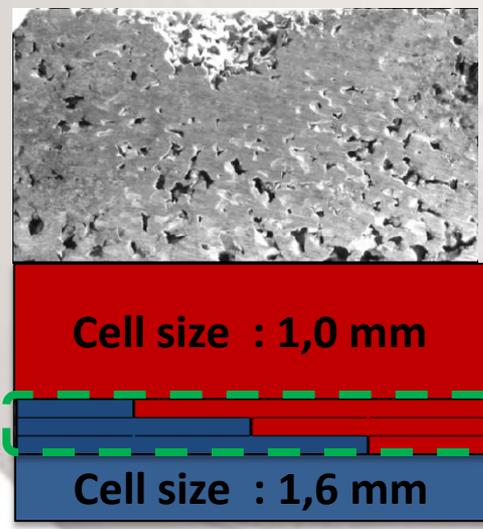
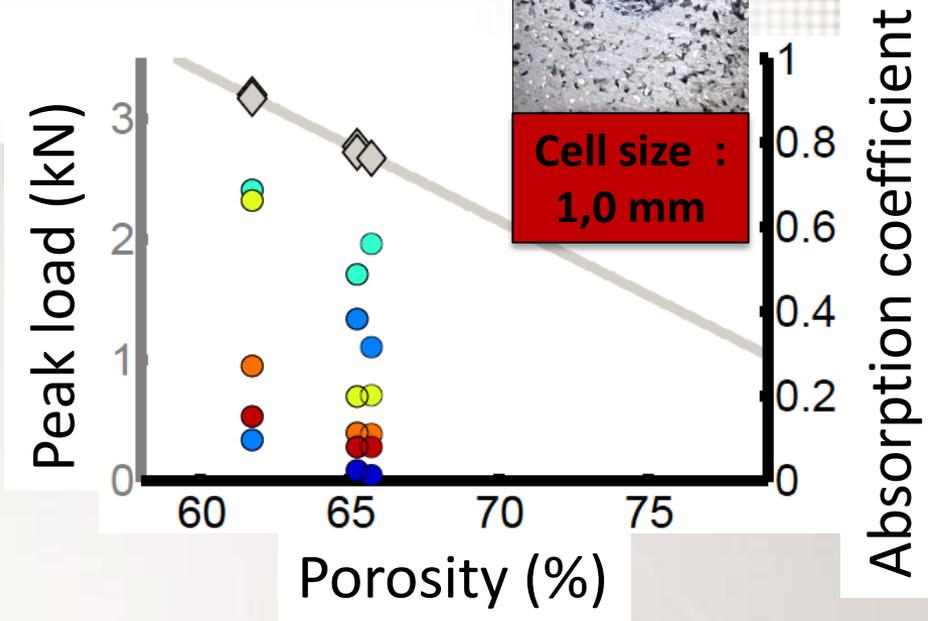
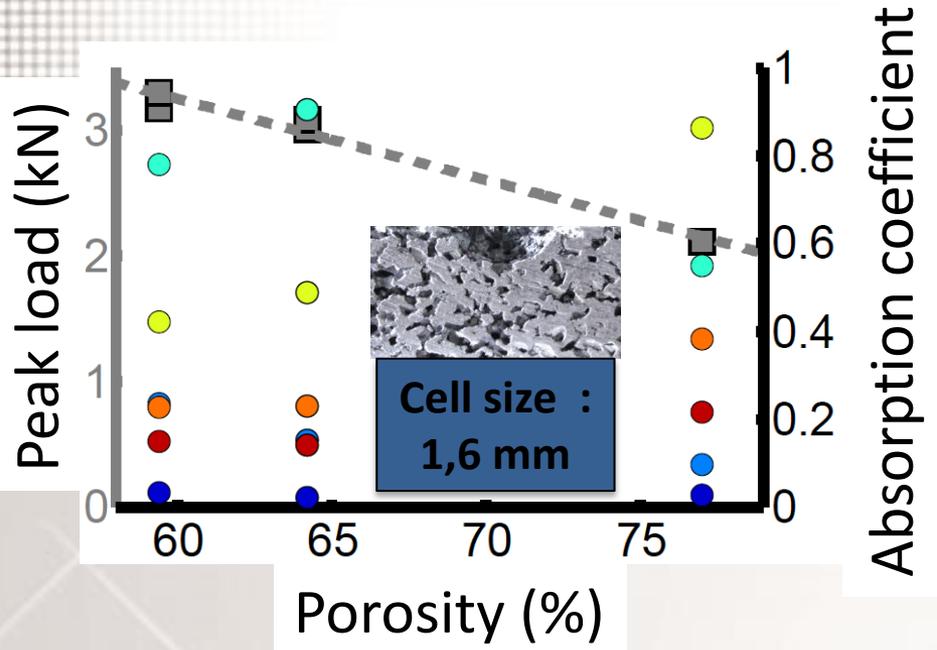
Cell size : 1,0 mm

Impact test



**Cell size :
1,6 mm**





Conclusions

- Inhomogeneous porous media → porosity profile
 - Constant microstructure
 - Homothetic transformation (associated with conformal transformation)
 - Parallel approach (2 external layers)
- Parameters profile (flexible foam)
 - Carman-Kozeny relationship
 - → Simple approach to inhomogeneous porous material
- Comparison criteria, impact - acoustics



Séries de Peano

Soient données les équations différentielles linéaires homogènes

$$\frac{dx_1}{dt} = r_{11}x_1 + \cdots + r_{1n}x_n$$

.....

$$\frac{dx_n}{dt} = r_{n1}x_1 + \cdots + r_{nn}x_n$$

(Voir, Peano, G. (1888). *Intégration par séries des équations différentielles linéaires*. *Mathematische Annalen*, 32(3), 450-456.)

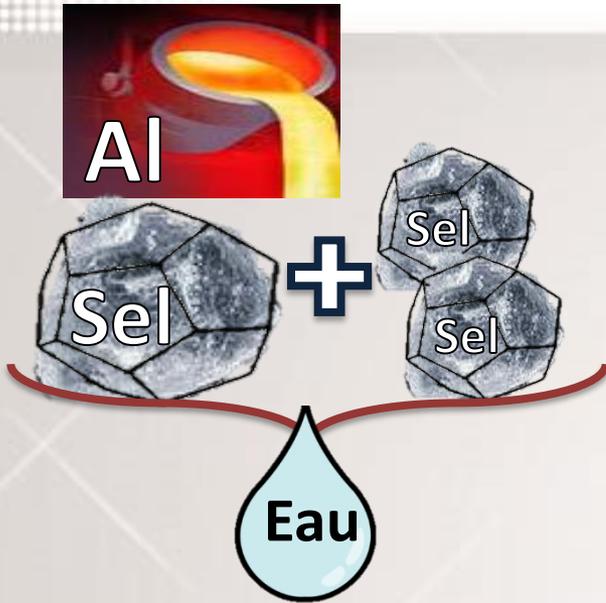
où les r_{ij} sont des fonctions réelles de la variable t , continues dans l'intervalle (p, q) , auquel appartiennent toutes les valeurs t_r que nous allons considérer. Que l'on substitue dans les seconds membres des équations proposées, à la place de $x_1 \dots x_n$, n constantes arbitraires $a_1 \dots a_n$, et que l'on intègre entre t_0 et t ; on obtiendra n fonctions $a'_1 \dots a'_n$ de t . Que l'on substitue de même dans les seconds membres des équations proposées, à la place de $x_1 \dots x_n$ des fonctions $a'_1 \dots a'_n$, et que l'on intègre de t_0 à t ; on obtiendra n fonctions $a''_1 \dots a''_n$. En opérant sur $a''_1 \dots a''_n$ comme on a fait sur $a'_1 \dots a'_n$, on obtiendra les fonctions $a'''_1 \dots a'''_n$, et ainsi de suite.

Les n séries

$$x_1 = a_1 + a'_1 + a''_1 + \cdots, \quad \dots, \quad x_n = a_n + a'_n + a''_n + \cdots$$

seront convergentes pour toutes les valeurs de t dans l'intervalle (p, q) ; leurs sommes sont des fonctions de t qui satisfont aux équations données, et qui, pour $t = t_0$, prennent les valeurs $a_1 \dots a_n$.”

Mousses bicouche métalliques et approche de gradient de propriétés



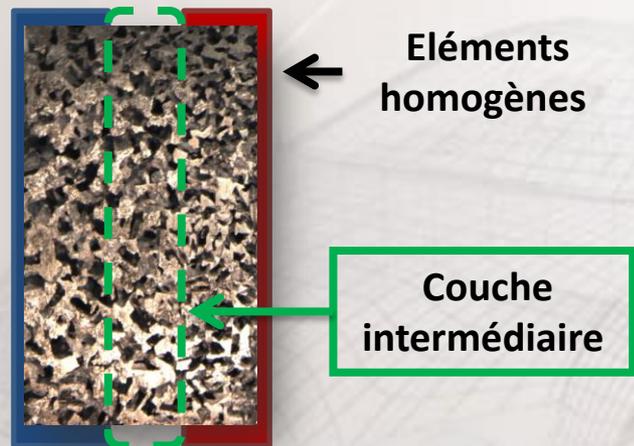
Élément homogène

Modèle de fluide équivalent JCA

Matrice de transfert: $[T_i]$

Série:  + 

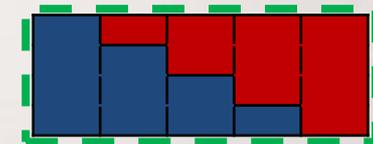
Parallèle*:  + 



Mousse bicouche métallique

Approches de gradient de propriétés

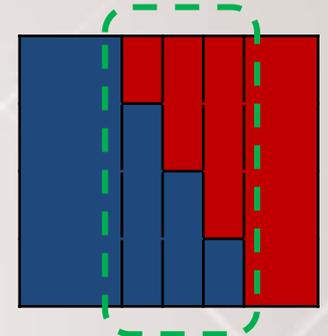
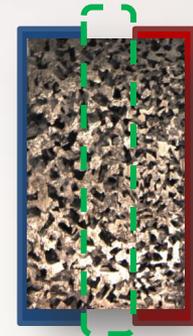
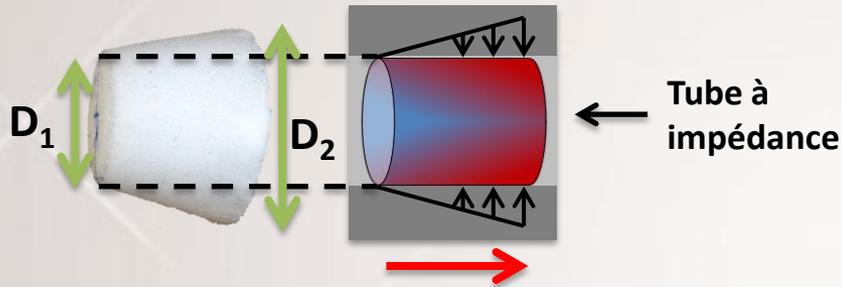
Parallèle/série:



* K. Vardier et al. JASA, 2013 « Transfer matrix method applied to the parallel assembly of sound absorbing materials. 134 (6) »

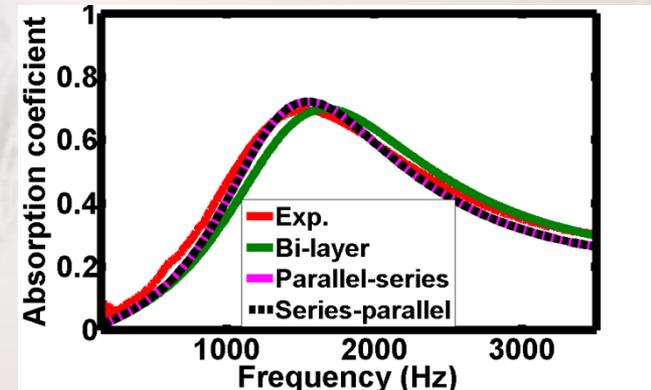
Validation de l'approche / Mousse bicouche métallique

Validation de l'approche simplifiée



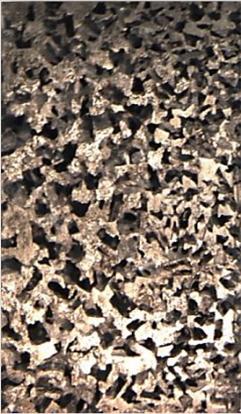
Hypothèses:
Tortuosité cte
Kozeny-Carman

Variation continue de:
(ϕ , σ , Λ , Λ')

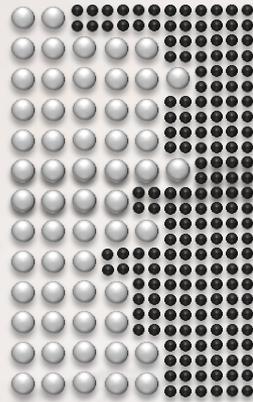


Problématique

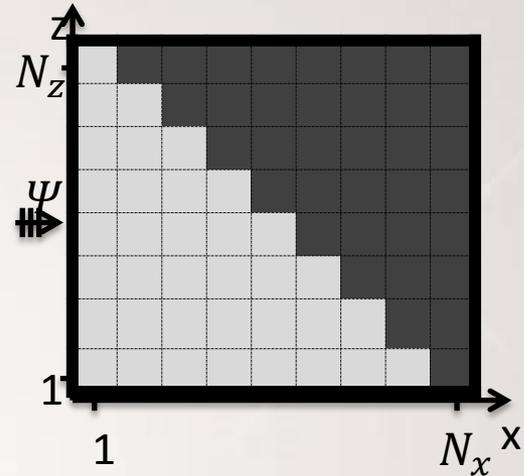
Mousse bicouche
métallique



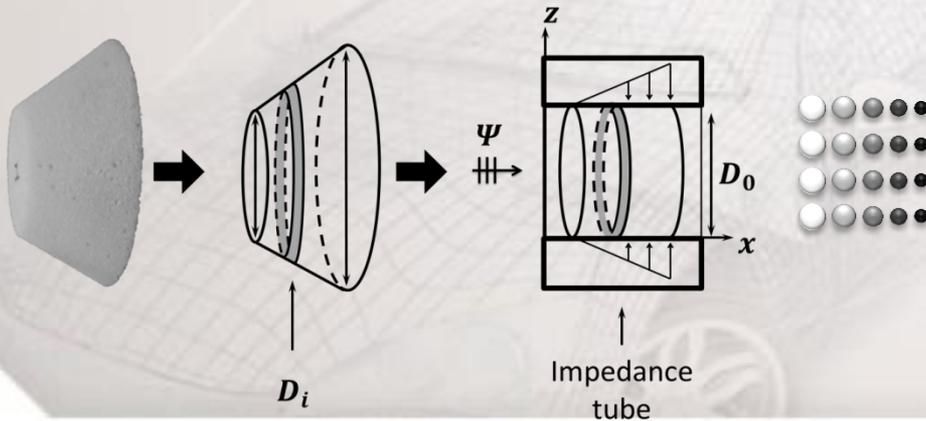
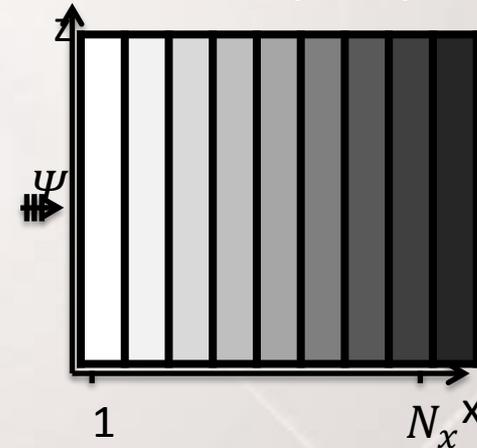
Matériau poreux
inhomogène

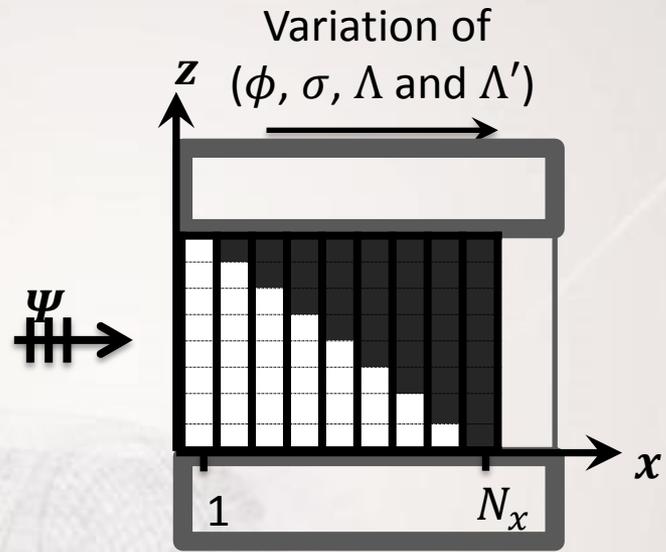
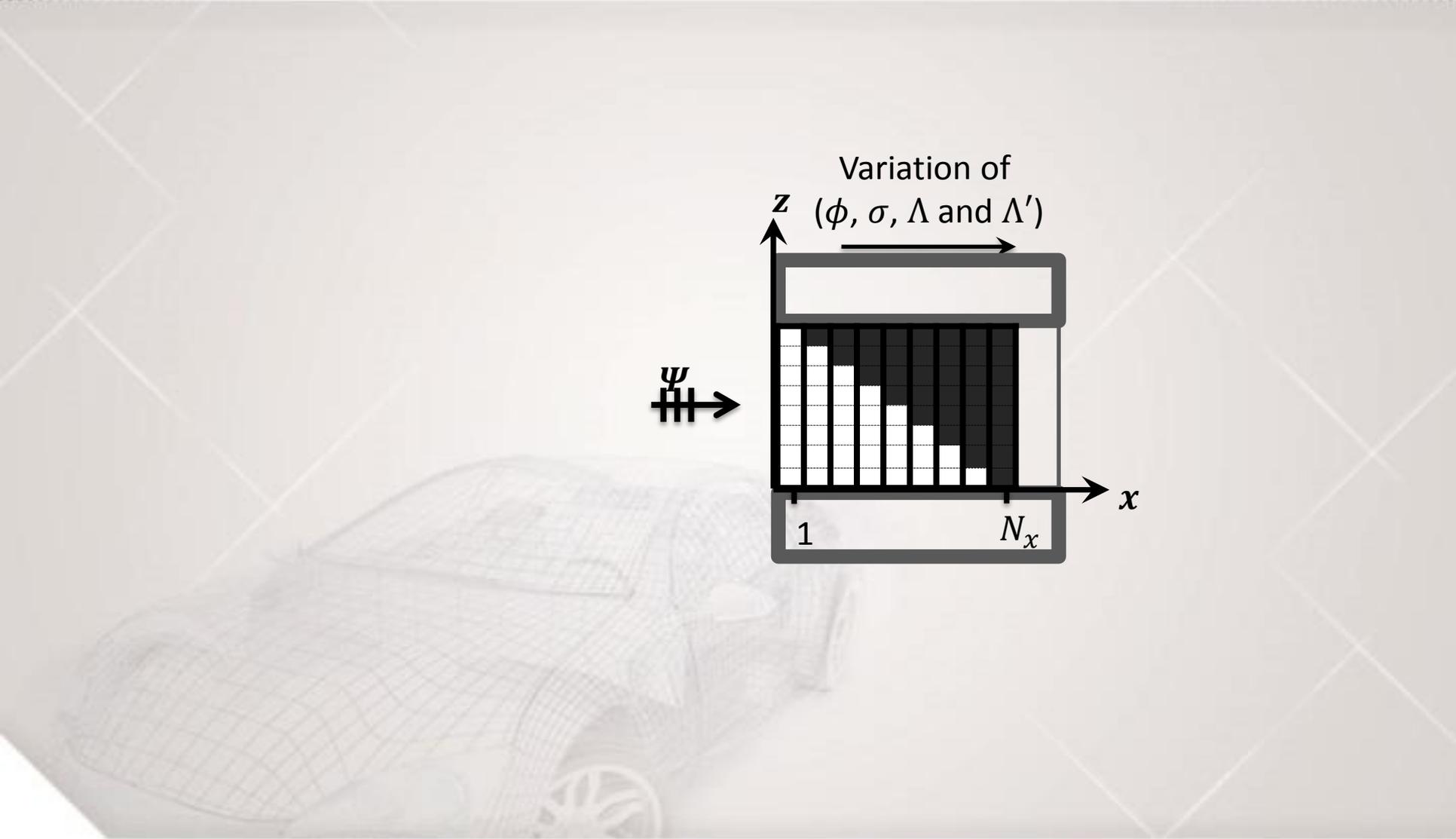


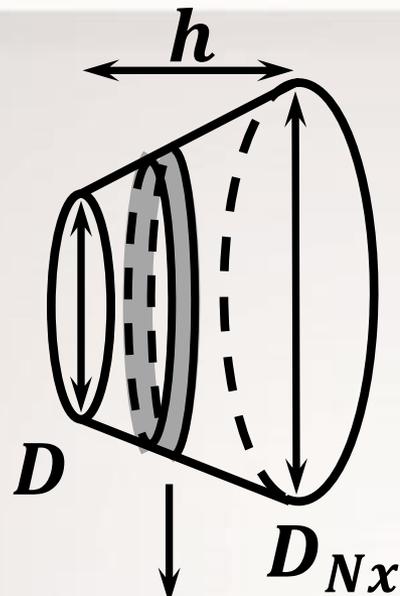
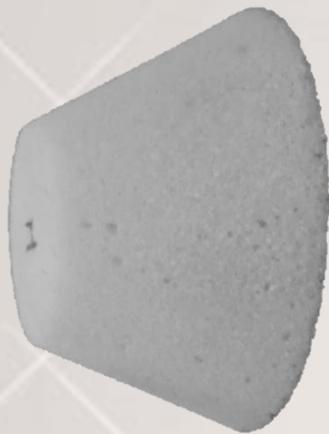
« mixture » approach



multiple layers

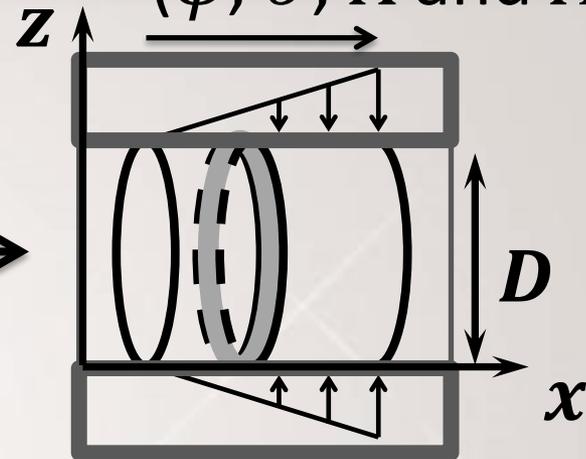




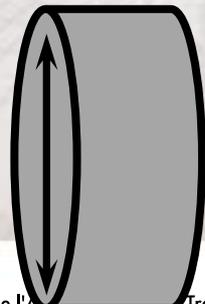
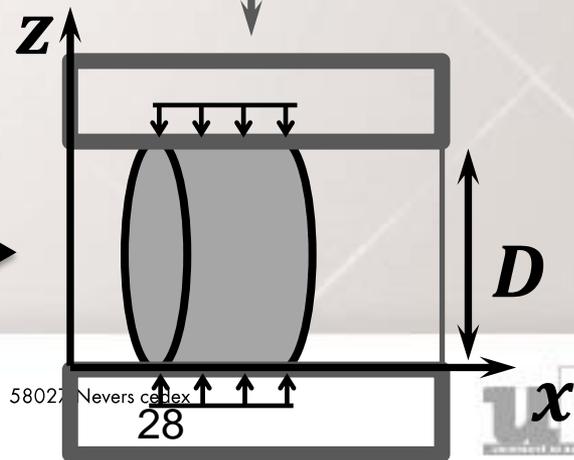


Ψ

Variation of
(ϕ , σ , Λ and Λ')



Impedance
tube



Ψ

