Fast identification of mechanical and coupling parameters of porous materials by sensitivity analysis: application to conventional and auxetic foam

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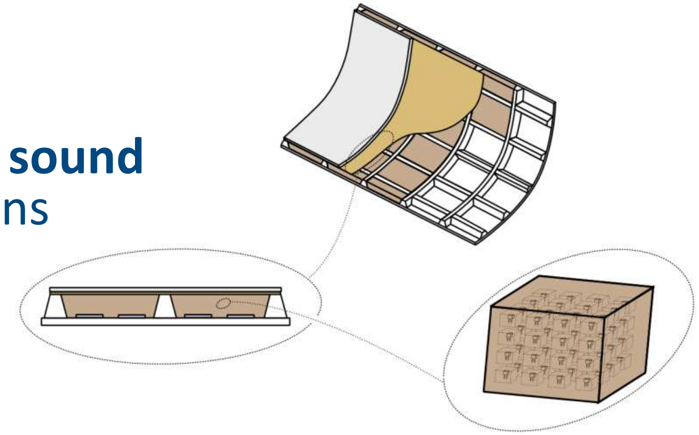
Summary

- Introduction
- Model description
- Sensitivity analysis
- Application on Melamine foam
- Application on PU-PE auxetic foam
- Conclusions

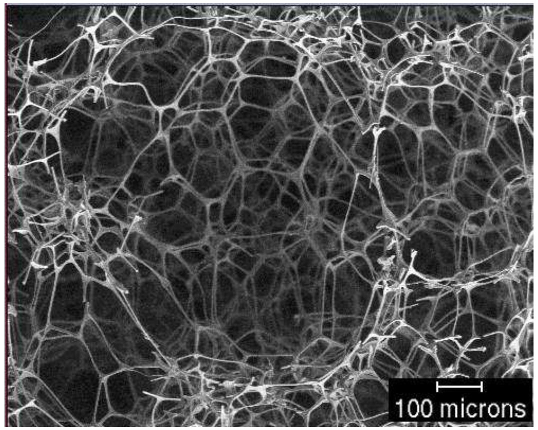
Introduction



- Use of porous materials for **smart vibroacoustics**
- Investigate new ways to **improve LF efficiency of sound packages:** use of passive resonant/active inclusions
- **Model-based** concepts
- Need for **fast**, **focused** identification procedures
- Case of **porous** materials : high number of parameters
  - Dedicated set-up for each parameter
  - Model updating from global information
- **Sensitivity** of parameters for **outputs of interest**?
- **Biot-Allard** model

Biot-Allard Model

- **Porous material: Two coupled phases (solid, fluid)**
- **Biot Theory:**
  - 'Macroscopic scale'
  - Representative elementary volume
- **Homogeneous material**
- **Solid skeleton: Hooke's law of linear-elasticity**
- **Pore space: saturated by the fluid phase**
- **Parameters (case of isotropic material):** E, ν, η, ρ, Φ, σ, α_∞, Λ , Λ'



gtmma.sourceforge.net/

Stress-strain equations: transversely-isotropic vs. isotropic

Transversely isotropic materials:

$$\sigma_{xx}^{s} = (2G+A)e_{xx} + Ae_{yy} + Fe_{zz} - (1-\phi)p$$

$$\sigma_{yy}^{s} = Ae_{xx} + (2G+A)e_{yy} + Fe_{zz} - (1-\phi)p$$

$$\sigma_{zz}^{s} = Fe_{xx} + Fe_{yy} + Ce_{zz} - (1-\phi)p$$

$$\sigma_{yz}^{s} = 2G'e_{yz}$$

$$\sigma_{xz}^{s} = 2G'e_{xz}$$

$$\sigma_{xy}^{s} = 2Ge_{xy}$$

where:

$$A = \frac{E\left(E'\nu + E\nu'^2\right)}{(1+\nu)\left(E' - E'\nu - 2E\nu'^2\right)}$$

$$F = \frac{EE'\nu'}{E' - E'\nu - 2E\nu'^2}$$

$$C = \frac{E'^2(1-\nu)}{E' - E'\nu - 2E\nu'^2}$$

$$G = \frac{E}{2(1+\nu)}$$

For isotropic materials: $G = G',\quad F = A,\quad C = A + 2G$

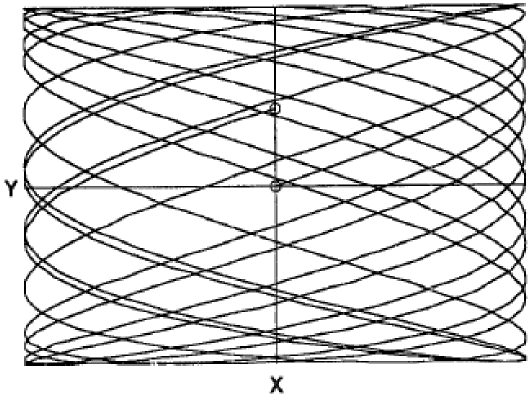
Parameters	**Melamine (isotropic?)**	**Auxetic (transv. Isotropic?)**
Mechanical	E, ν, η, ρ	E, E’, ν, ν,’ η, ρ
Coupling	Φ, σ, α∞, Λ , Λ’	Φ, σ_x, $\sigma_{y,}$ $\alpha_{\infty x,}$ $\alpha_{\infty y}$, Λ_x, Λ_y, Λ’

Sensitivity analysis

- **Sensitivity analysis**
  - **Inputs**: Foam parameters
  - **Outputs** of interest: Z, α (frequency-dependent)
  - **OAT sensitivity index** : finite differences
  - Parameters **hierarchisation** and **screening**

$$s \approx \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

- **FAST technique**
  - Based on **variance** analysis
  - Estimation of **sensitivity indices**
    - First order / Total sensitivity index
    - TSI(A) = SI(A) + SI(AB) + SI (AC) + SI(ABC)
  - (pseudo) **periodic sampling strategy** in the design space, **FFT** to estimate the SIs



Fourier-transform sensitivity analysis, G. Colonna, S. Longo, F. Esposito, M. Capitelli, Applied Physics B, 1994

Parameters ranges
Melamine sensitivity analysis

Coupling parameters			
Parameters	**Unit**	**Lower bounds**	**Upper bounds**
Φ	**[-]**	**0.98**	**0.99**
σ	**Nsm^{-4}**	**9000**	**11000**
α_∞	**[-]**	**1**	**1.03**
Λ	**[µm]**	**80**	**100**
Λ’	**[µm]**	**100**	**300**
Mechanicals parameters			
Parameters	**Unit**	**Lower bounds**	**Upper bounds**
E	**[kPa]**	**100**	**300**
ν	**[-]**	**0.14**	**0.45**
ρ	**Kgm^{-3}**	**8.5**	**14.5**
η	**[%]**	**5**	**15**

NB Not always easy to obtain confident information about parameters ranges…

Melamine sample 4,7 cm

Frequency range of interest

200-1600 Hz

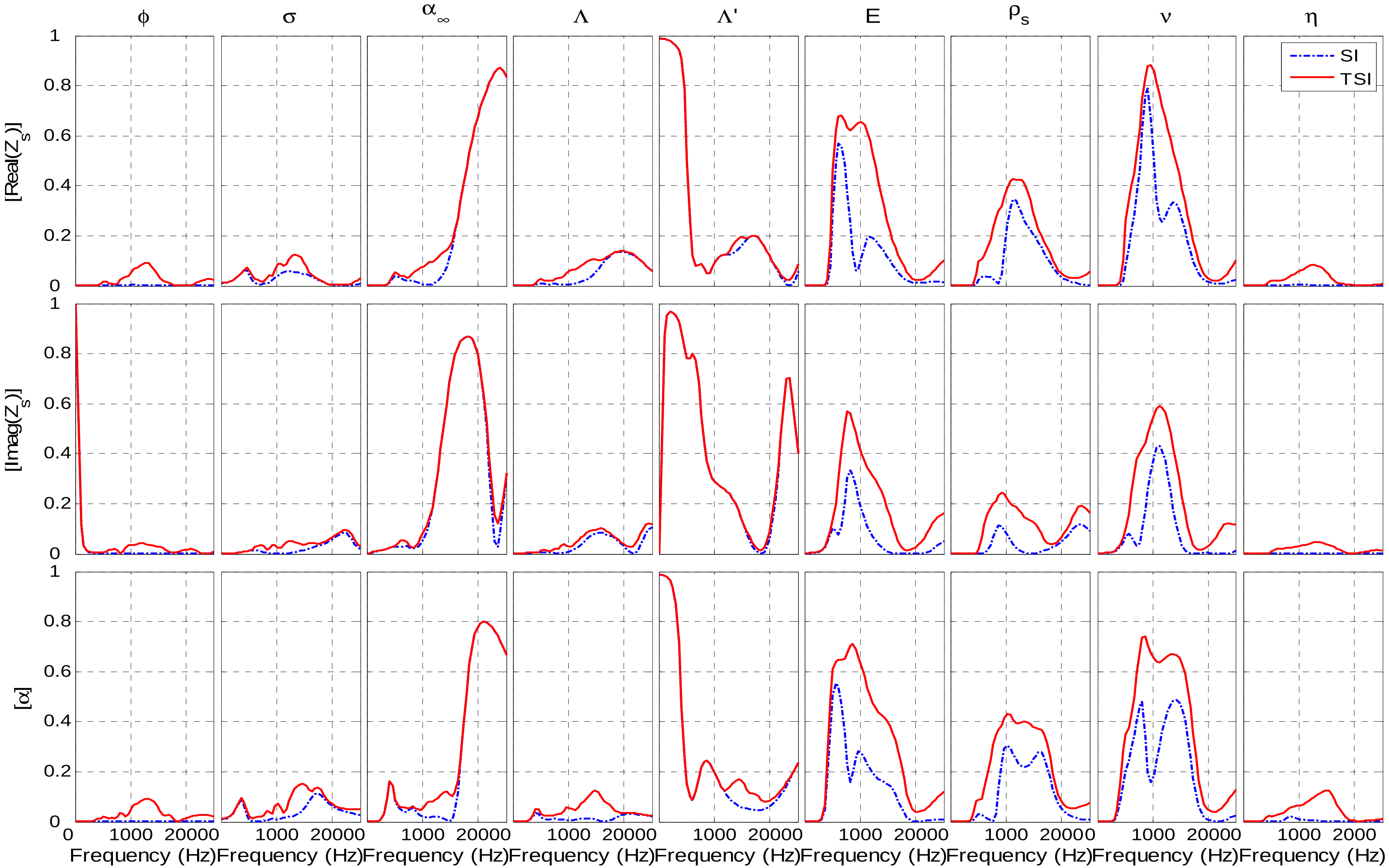
Outputs of interest

α, Z

(incident plane wave, sample backed by an impervious rigid wall)

Small ranges, analytic formulation => fast convergence

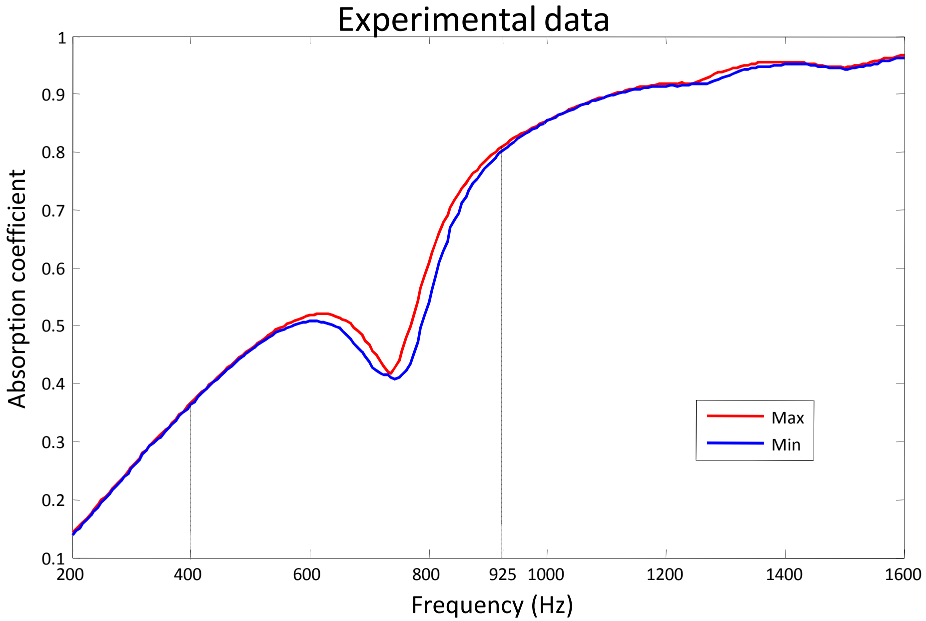
Sensitivity analysis results: Melamine sample



Parameters identification: Melamine

- **Weighted Cost function for n tests on Nf frequency samples:**

$$G = \sum_{i=1}^{Nf} w_i \, g(\omega_i)$$



$$g(\omega) = w_\alpha \left| \frac{\alpha(\omega) - \alpha_e(\omega)}{\alpha_e(\omega)} \right| + w_Z \left| \frac{|Z(\omega)| - |Z_e(\omega)|}{|Z_e(\omega)|} \right|$$

$$\alpha_e \frac{1}{n} \sum_{i=1}^{n} \alpha_e^{(i)}$$

Strategies for model updating

- **Simulation 1**

All parameters together

- **Simulation 2**

Most important parameters

Λ', ν, E , ρ

- **Simulation 3**

1°) Most important parameters

Λ', ν, E ,ρ

2°) Second level parameters

$\alpha\infty$, σ, Λ

- **Simulation 4**

1°) Most important parameters

Λ', ν, E ,ρ

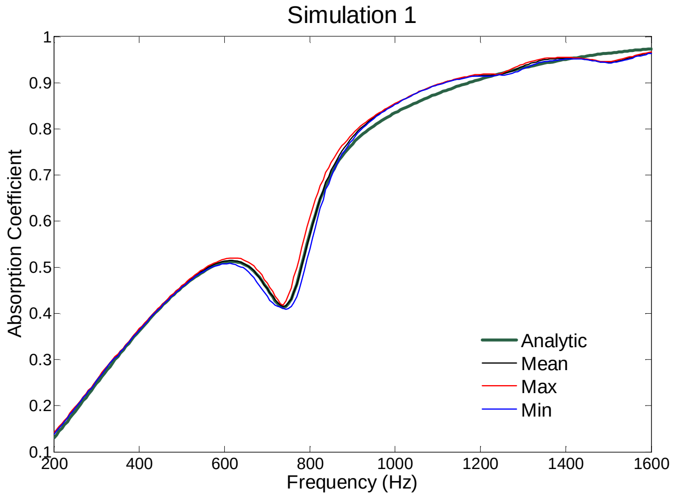
2°) Second level parameters

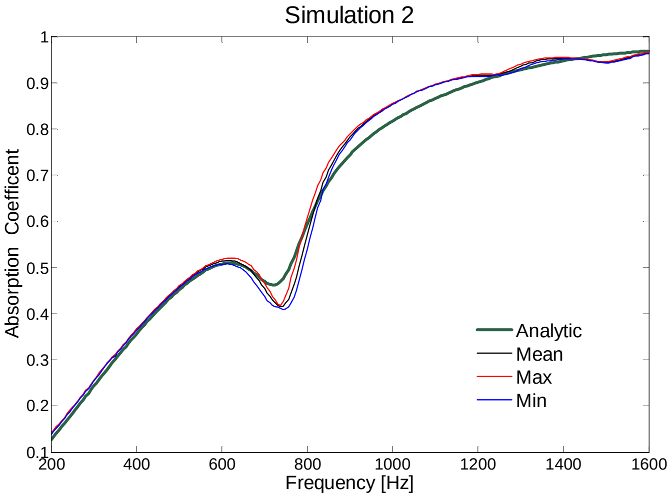
$\alpha\infty$, σ, Λ

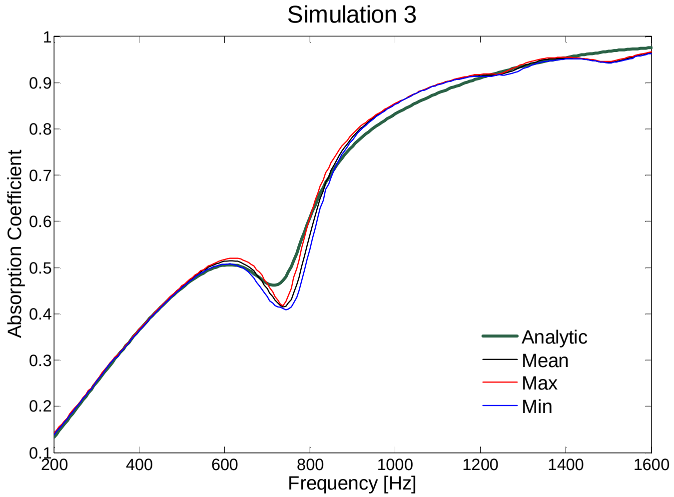
3°) Less important

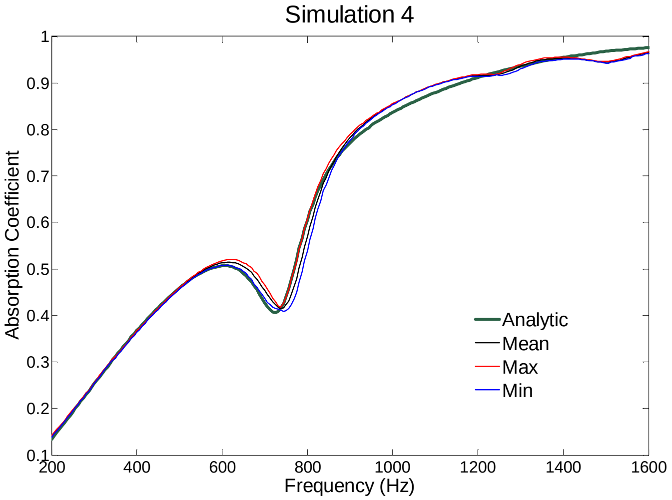
Φ, η

Absorption coefficient for Melamine foam

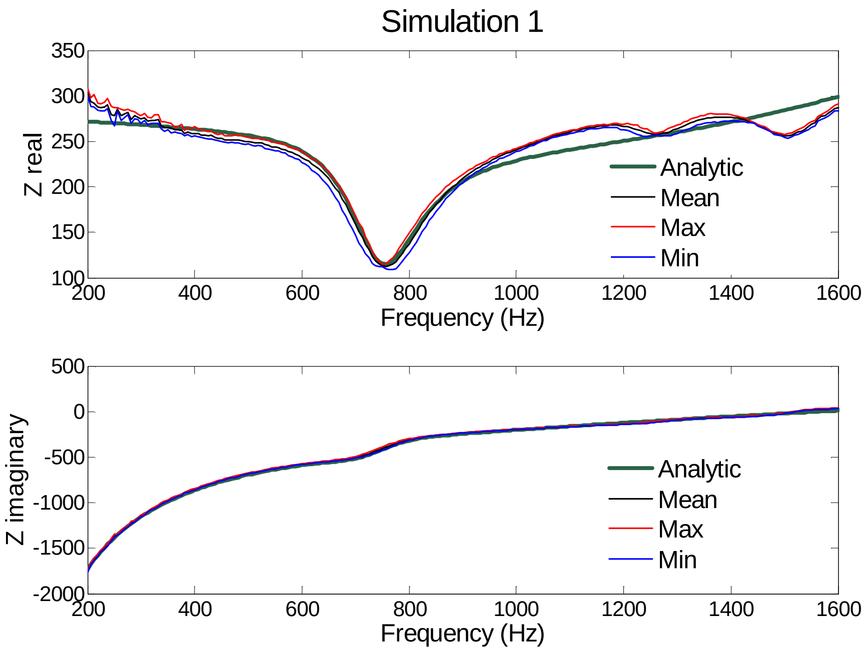

Simulation 1

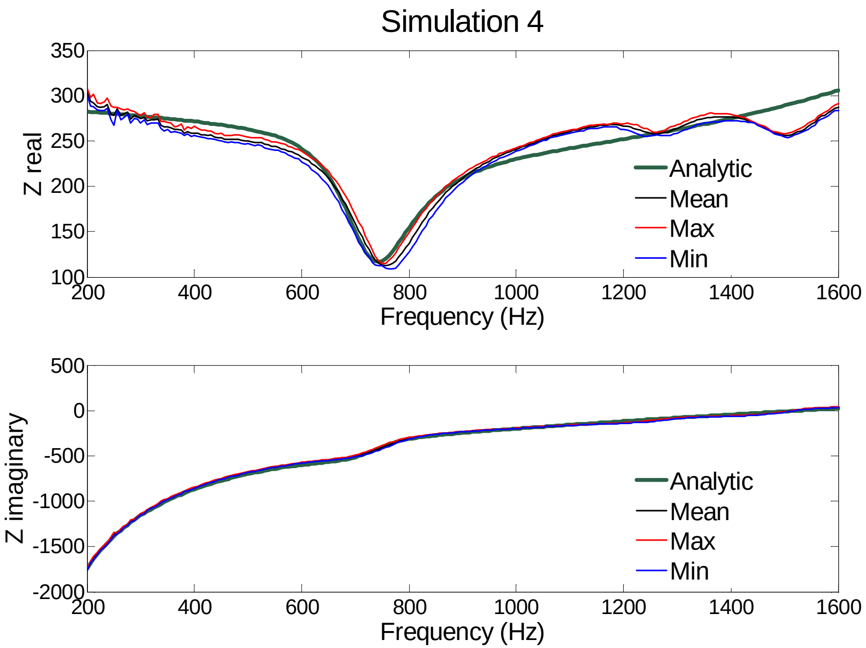

Simulation 2


Simulation 3


Simulation 4

Acoustic impedance for Melamine foam





Results of model updating for melamine foam

Parameters	Simulation			
	1	2	3	4
Λ'[µm]	168	177	177	177
E [kPa]	213	207	207	207
ν [-]	0.302	0.299	0.299	0.299
ρ [Kgm^{-3}]	14.5	14.5	14.5	14.5
α_∞ [-]	1	1	1	1
σ [Nms^{-4}]	11000	10000	11000	11000
Λ [µm]	99.9	89.9	91.4	91.4
η [%]	0.138	0.100	0.100	0.056
Φ [-]	0.990	0.985	0.985	0.990
Cost function	14.6	24.7	18.5	16.3
Calculation time [s]	34.2	8.9	12.4	18.5

Auxetic vs. Melamine

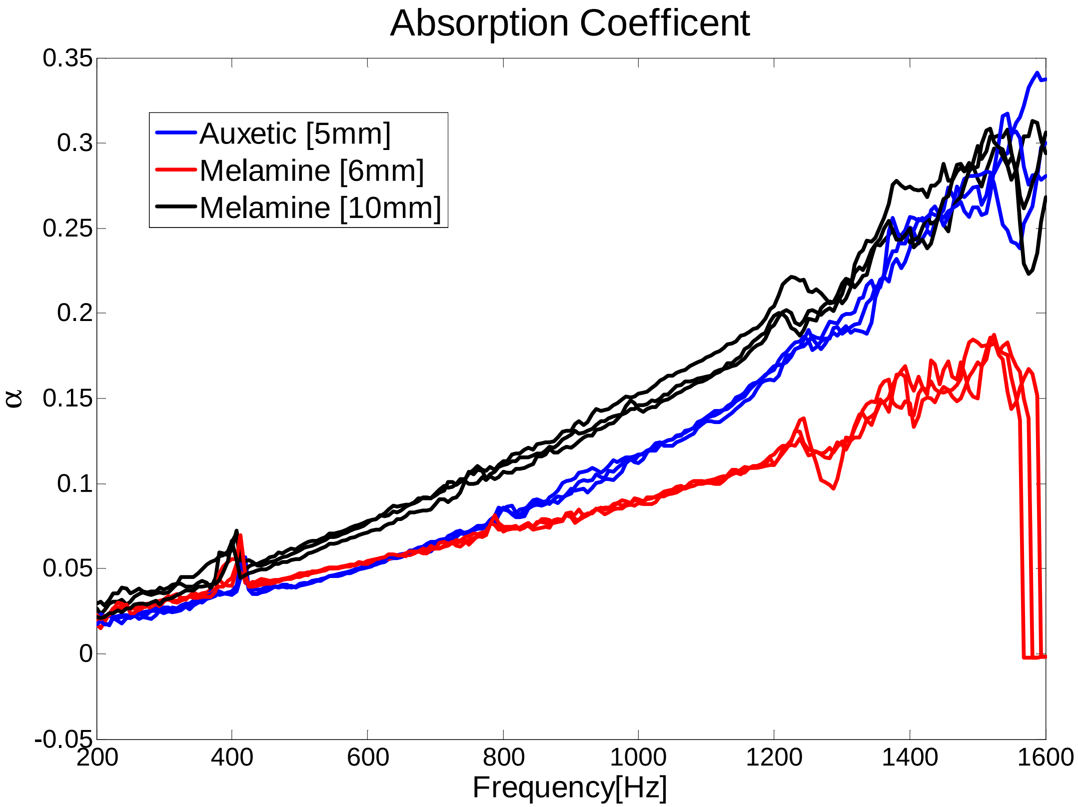
Classical PU-PE foam

↓

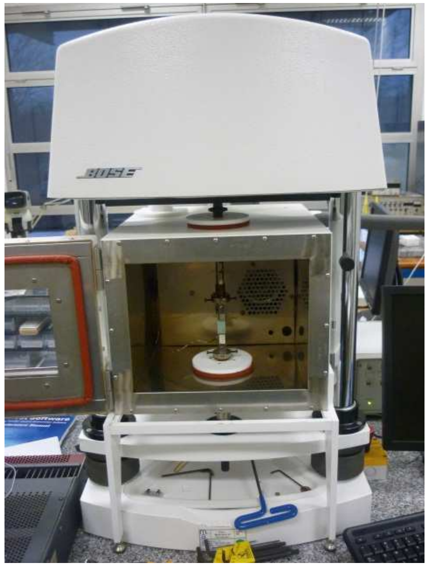
Specific process

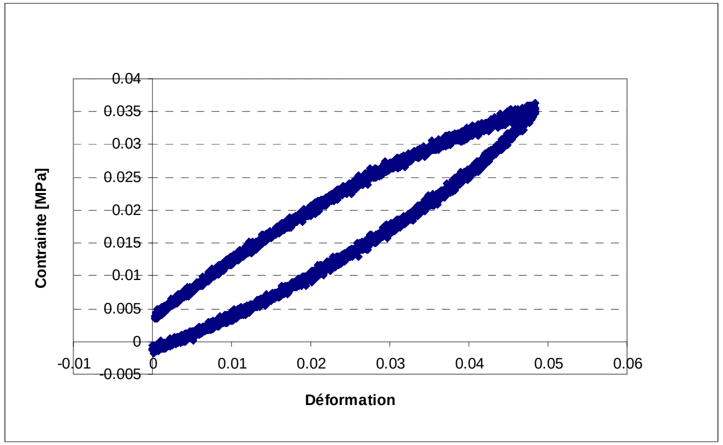
↓

Auxetic PU-PE foam



Dynamical Mechanical Analysis





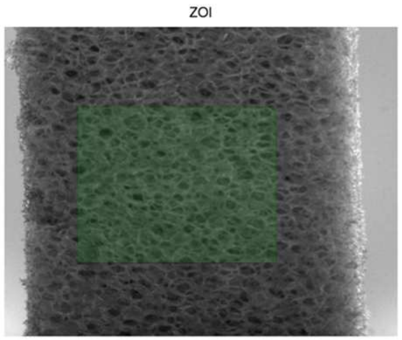
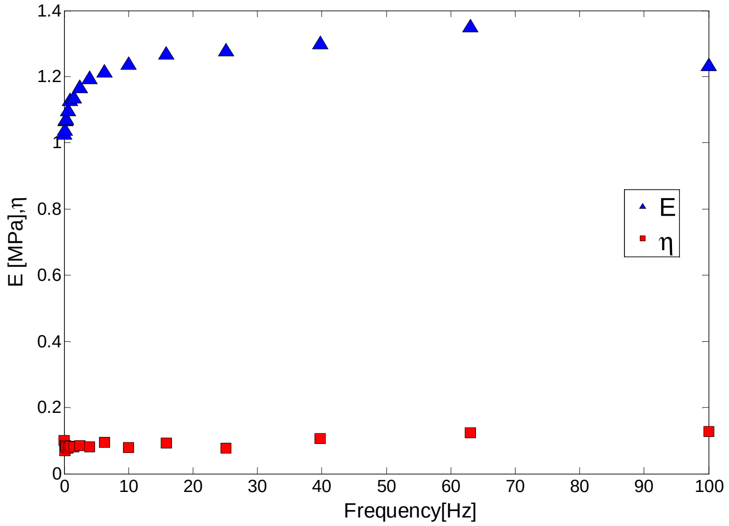


Image correlation

$-0.82<v<-0.1$



Auxetic sensitivity analysis parameters ranges?

Coupling parameters

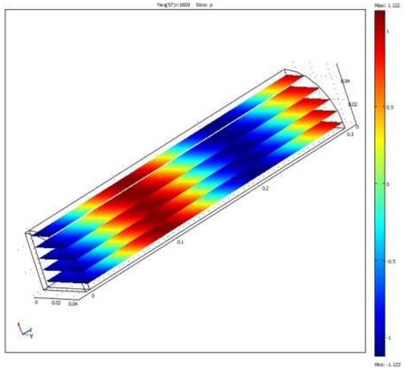
Parameters	Unit	Lower bounds	Upper bounds
Φ	[-]	0.70	0.99
σ	Nsm^{-4}	1500	200000
α_∞	[-]	1	2
Λ	[µm]	5	200
Λ'	[µm]	5	400

Mechanicals parameters

Parameters	Unit	Lower bounds	Upper bounds
E	[kPa]	1000	1400
E'	[kPa]	5	20
ν	[-]	0.25	0.35
ν'	[-]	-0.1	-0.82
ρ	Kgm^{-3}	20	34
η	[%]	0	25

Auxetic sample 5mm

FE analysis : more **complex geometries** & **excitations**, arbitrary **constitutive law**



Large ranges, FE formulation => slow convergence (not yet!)

Conclusion

- Identification of parameters for **global vibroacoustic indicators**
- Preliminary **parameters sensitivity analysis** to improve **efficiency** of model updating
- **Good results** for conventional melamine foam – all parameters required
- Case of **auxetic** foams :
  - **transversely isotropic** configuration
  - Interesting **acoustic properties**
  - work in progress: sensitivity analysis, parameters identification, correlation with DMA tests
- Next steps: use **validated model** for the design of the **smart foam**