

Mechanical behavior of Innovative Sandwich Materials

Ph.D. Student : Joulia Salloum

European Mechanics of Materials Conference (EMMC)

April 4th-6th 2022, University of Oxford

- Patrick Ienny (Director)
- Loïc Daridon (Co-Director)
- Romain Léger (Supervisor)

1. Introduction & Objectives

- Commercial vessels (eco-design, etc.)
- Materials for marine applications :
 - Polymer matrix laminated composite materials
*(epoxy or vinylester resin / carbon fiber
polyester resin / fiberglass)*
 - Sandwich materials *(lightness / bending stiffness)*
(polymer matrix laminates + polymer foam or/and wood)



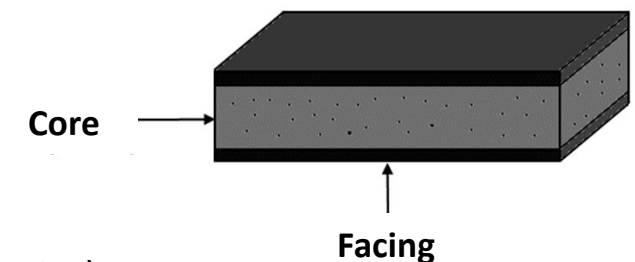
The aim is to predict a material substitution by materials related to sustainable development

Reference materials :

- PVC80 foam
- Monolithic made of **fiberglass** and **polyester resin**

Substitute materials :

- PETr80 foam (same density) / PETr115 (equivalent mechanical properties)
- Monolithic made of **basalt fiber** and **greenpoxy resin** (SICOMIN)



2. Approaches / Works

- Foam

→ Experimental tests : validate the hypothesis of the mechanical behavior

→ Identification of macrohomogeneous behavior : FEMU method

→ Multi-scale approach

→ Morphological characterization: MO and SEM

→ Homogenized foam behavior

- Monolithic

→ Homogenized behavior: damageable elasticity (cohesive zones - CZM)

(multi-scale approach : fiber strands, ply, multi-ply composite, etc.)

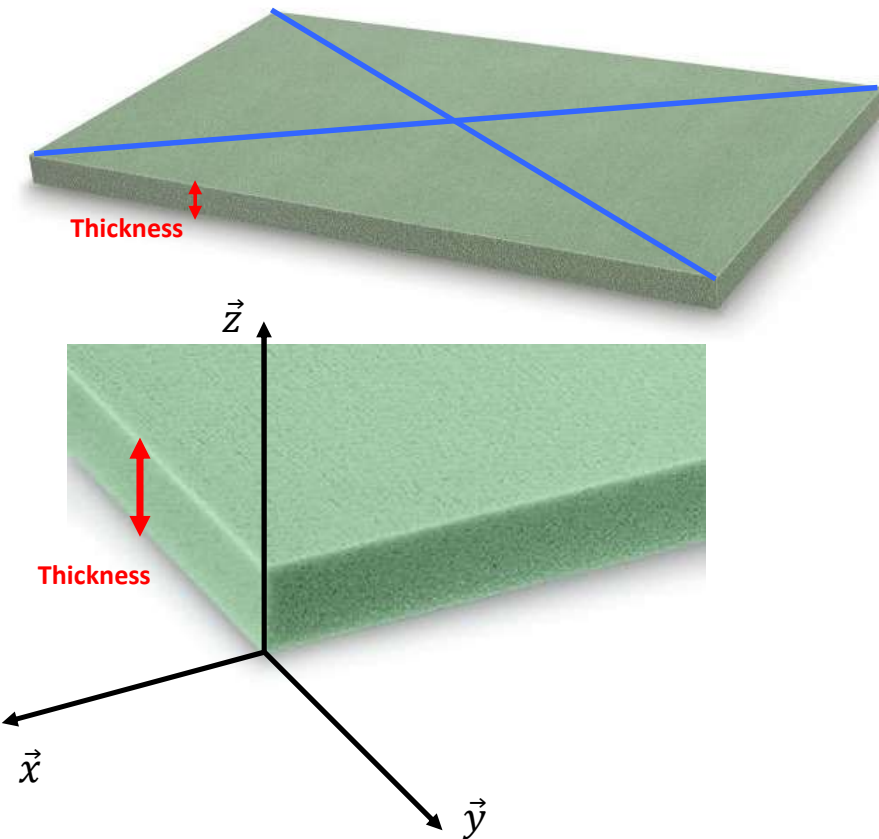
- Sandwich

→ Construction of a model : homogenized behavior of the complete sandwich material

(foam + monolithic facings)

3. Experimental part

PVC foam (reference material)



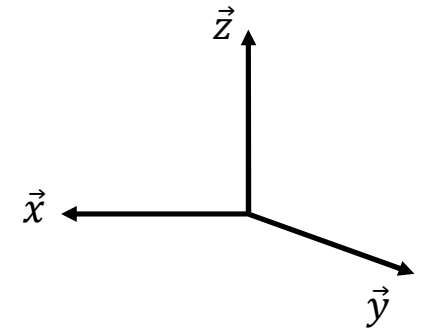
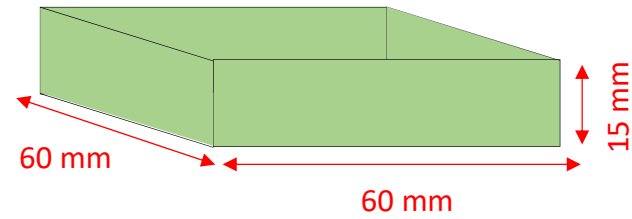
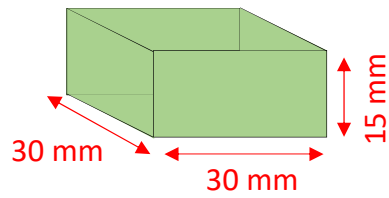
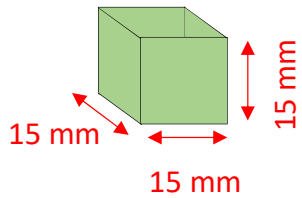
$$\bar{\bar{S}} = \begin{bmatrix} 1/E_y & -\nu_{xy}/E_y & -\nu_{zy}/E_z & 0 & 0 & 0 \\ -\nu_{yx}/E_y & 1/E_y & -\nu_{zx}/E_z & 0 & 0 & 0 \\ -\nu_{yz}/E_y & -\nu_{xz}/E_y & 1/E_z & 1/G_{xy} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{xz} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{xz} \end{bmatrix}$$

$\bar{\bar{S}}$: compliance matrix of an elastic transversely isotropic material (\vec{z} axis)

- Compression test, \vec{y} direction : E_y, ν_{yz}
- Compression test, \vec{z} direction : E_z, ν_{zy}
- Shear test, (\vec{x}, \vec{z}) plan : G_{xz}

3. Experimental part

→ Compression tests (3 different slenderness ratios)



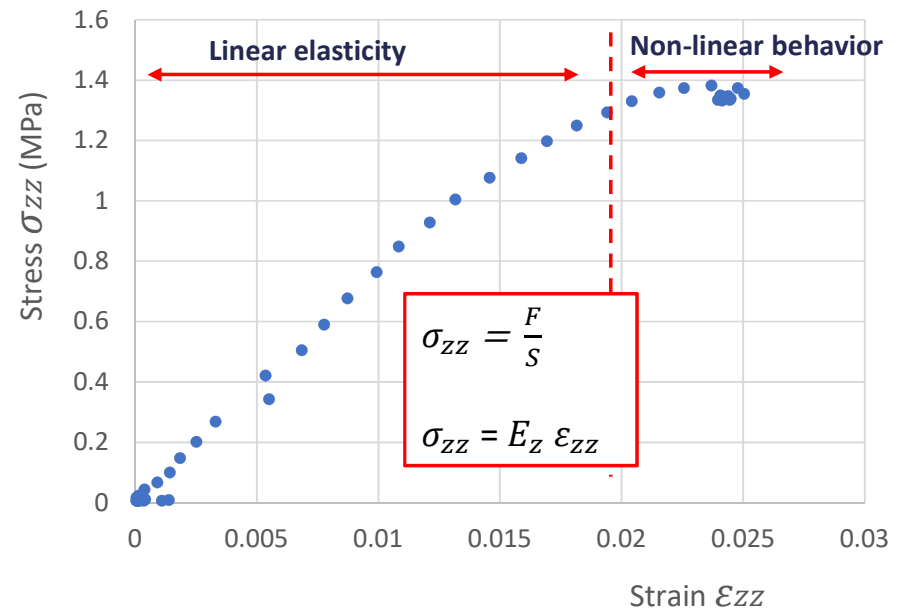
Digital Images Correlation



Uniaxial compression :

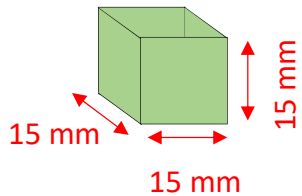
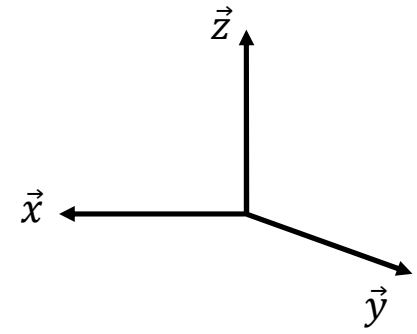
ratio minimum = 2 between height and width

Compression test on PVC 80 (15x15x15 mm³)

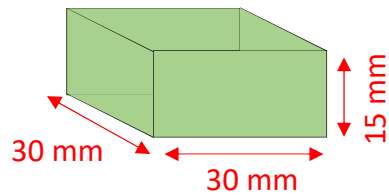


3. Experimental part

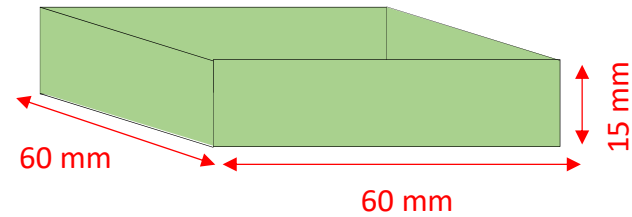
→ Compression tests (3 different slenderness ratios) : PVC80



$$\bar{E}_z = 76,5 \text{ MPa}$$



$$\bar{E}_z = 79.023 \text{ MPa}$$



$$\bar{E}_z = 92.63 \text{ MPa}$$

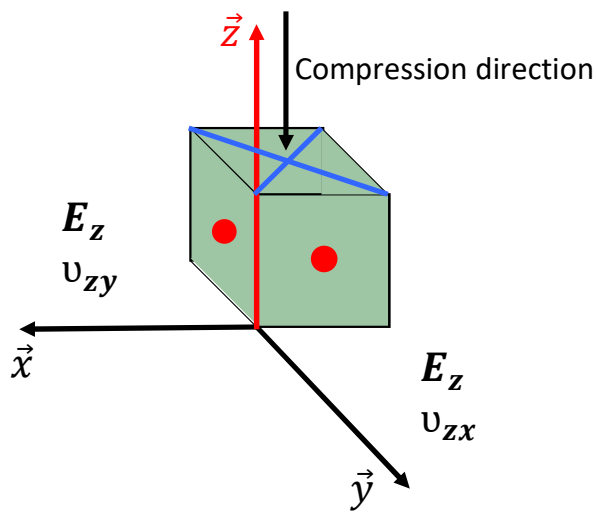
→ Different apparent modules for each set of dimensions for the same material
(*Triaxial compression*)

→ A FE model is needed to identify the intrinsic elastic parameters

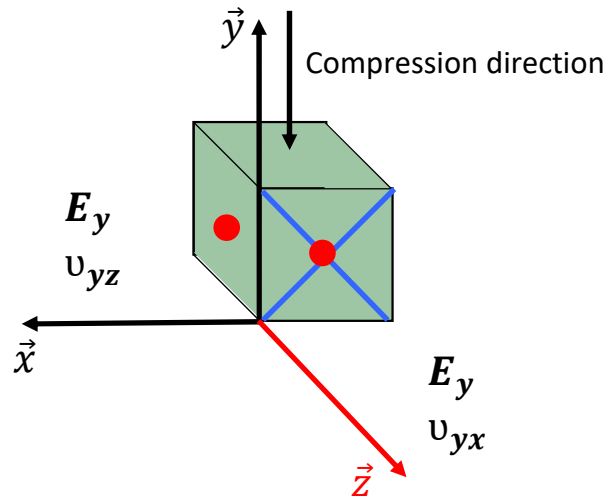
3. Experimental part

→ Compression tests $15 \times 15 \times 15 \text{ mm}^3$: 2 directions \vec{z} and \vec{y}

Thickness direction \vec{z}



Longitudinal direction \vec{y}



E_z and E_y : Apparent stiffness modules

ν_{zy} , ν_{zx} and ν_{yz} , ν_{yx} :
Apparent transverse contraction coefficients

Equation that verifies transverse isotropy :

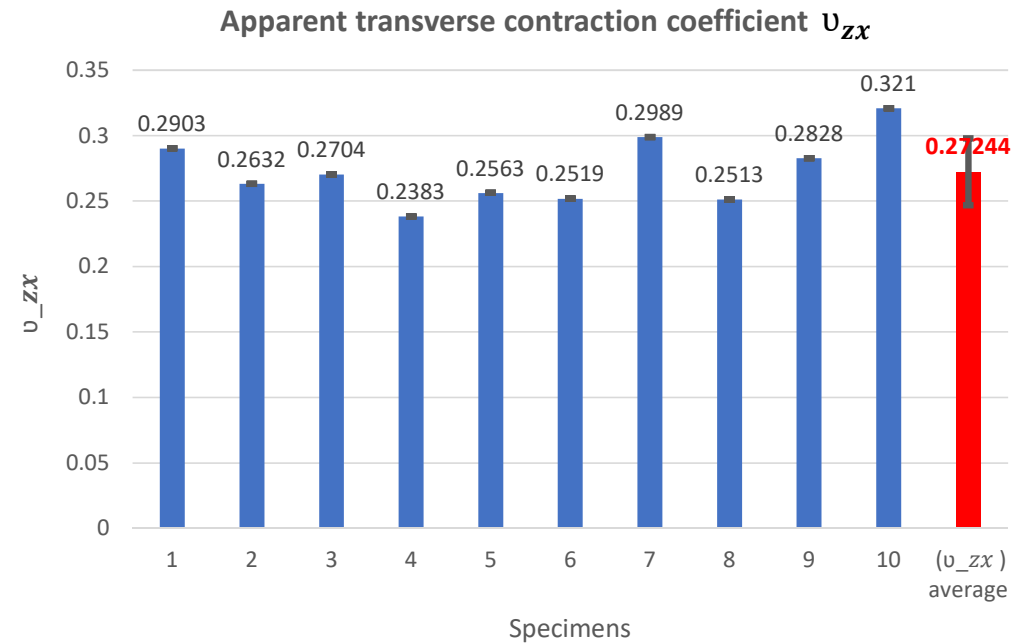
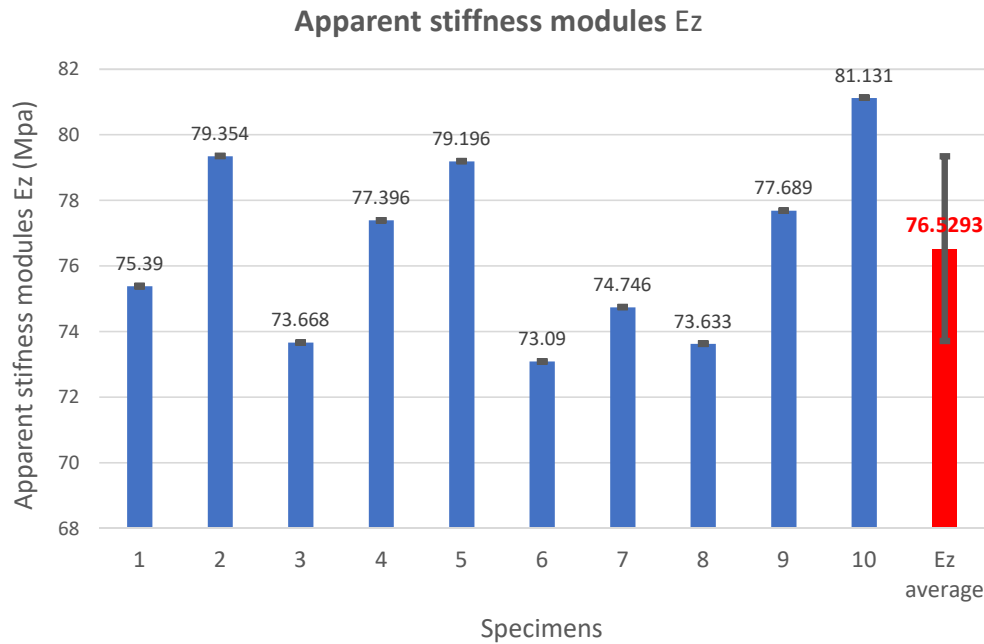
$$-\frac{\nu_{zx}}{E_z} = -\frac{\nu_{xz}}{E_x} = -\frac{\nu_{yz}}{E_y}$$

● : Face observed with the camera

✕ : indicates the top (or bottom) of the plate in which the cubes are cut

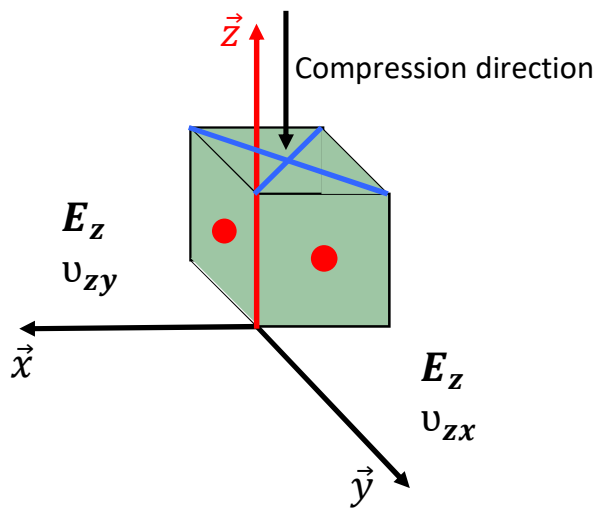
3. Experimental part

→ Example of compression tests PVC 80 15x15x15mm³ : directions \vec{z}



3. Experimental part

Thickness direction \vec{z}

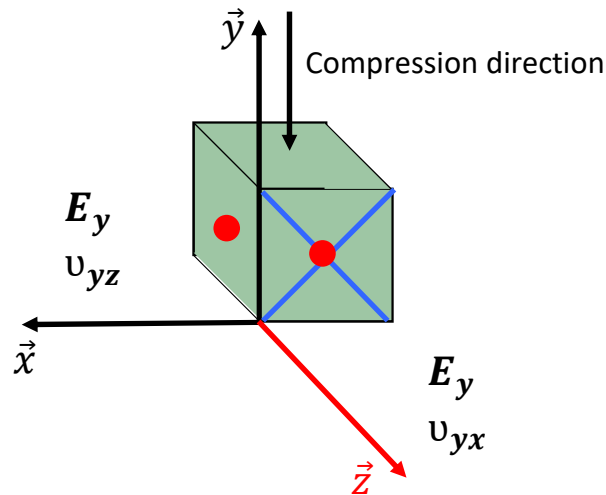


Results PVC80 :

$\Rightarrow \overline{E_z}$: Apparent stiffness module = 76,5 MPa

$\Rightarrow \overline{\nu_{zx}} = 0,272$

Longitudinal direction \vec{y}



Results PVC80 :

$\Rightarrow \overline{E_y}$: module apparent transversal = 49,5 MPa

$\Rightarrow \overline{\nu_{yz}} = 0,196$

Transverse isotropy
 \vec{z} axis



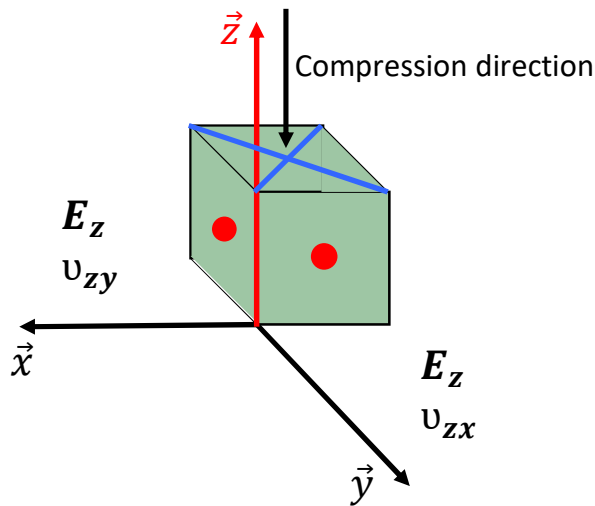
Verification of transverse
isotropy based on
apparent modules /
coefficients

$$\text{Ratio} = -\frac{\overline{\nu_{xz}}}{\overline{E_x}} = -\frac{\overline{\nu_{zx}}}{\overline{E_z}} = -\frac{0,272}{76,5} = -0,0036$$

$$\text{Ratio} = -\frac{\overline{\nu_{yz}}}{\overline{E_y}} = -\frac{0,196}{49,5} = -0,0039$$

3. Experimental part

Thickness direction \vec{z}



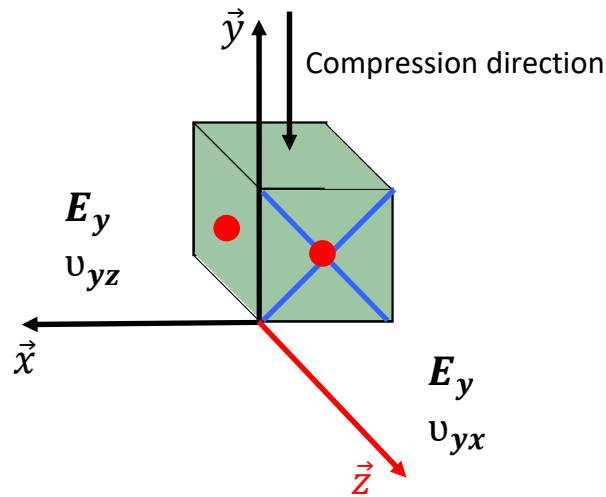
Results PETr80 :

$\Rightarrow \overline{E_z}$: Apparent stiffness module = 43,48 MPa

$\Rightarrow \overline{v_{zx}} = 0,47$

$$\text{Ratio} = -\frac{\overline{v_{xz}}}{\overline{E_x}} = -\frac{\overline{v_{zx}}}{\overline{E_z}} = -\frac{0,47}{43,48} = -0,0108$$

Longitudinal direction \vec{y}



Results PETr80 :

$\Rightarrow \overline{E_y}$: module apparent transversal = 20 MPa

$\Rightarrow \overline{v_{yz}} = 0,15$

$$\text{Ratio} = -\frac{\overline{v_{yz}}}{\overline{E_y}} = -\frac{0,15}{20} = -0,00075$$

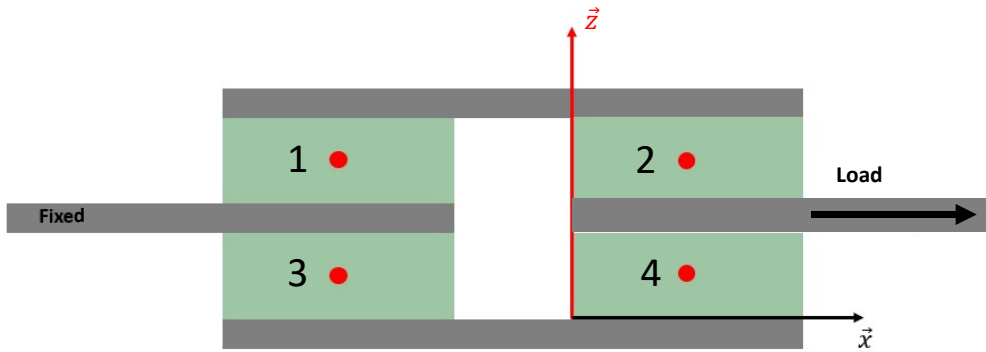
Transverse isotropy
 \vec{z} axis



Verification of transverse
isotropy based on
apparent modules /
coefficients

3. Experimental part

→ Shear test : (\vec{x}, \vec{z}) plan

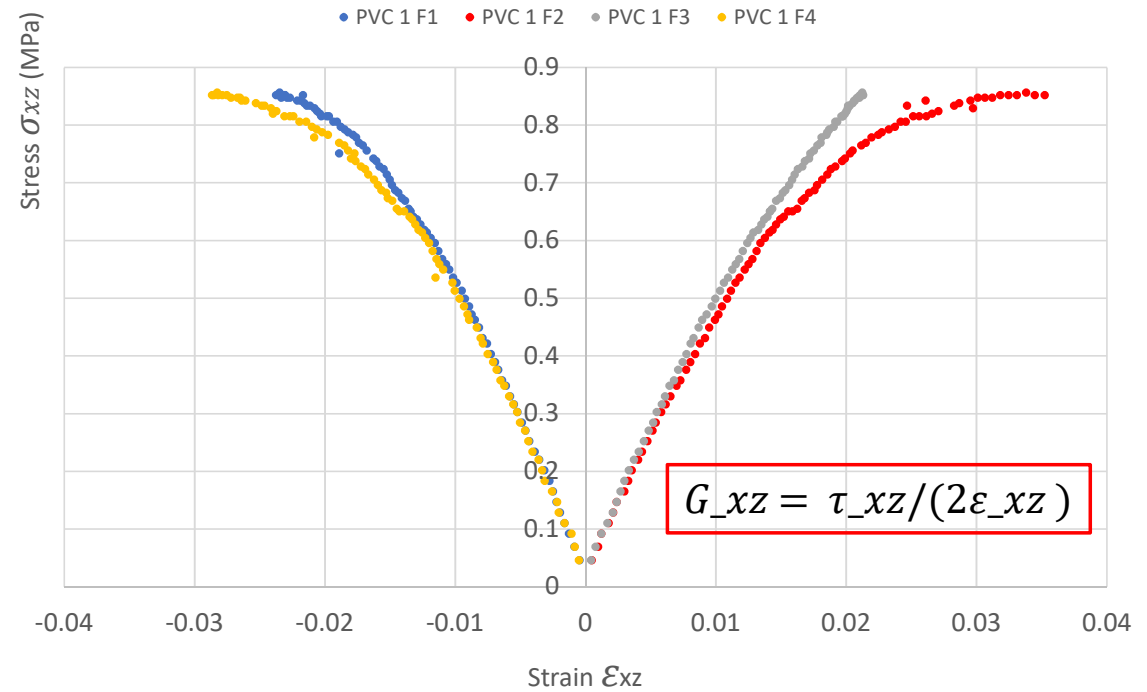


● : Face observed with the camera

Face	G_{xz} (MPa)
1	24,71
2	23,09
3	24,05
4	25,56

Average G_{xz} : 24,35 MPa
Standard deviation : 1,04 MPa

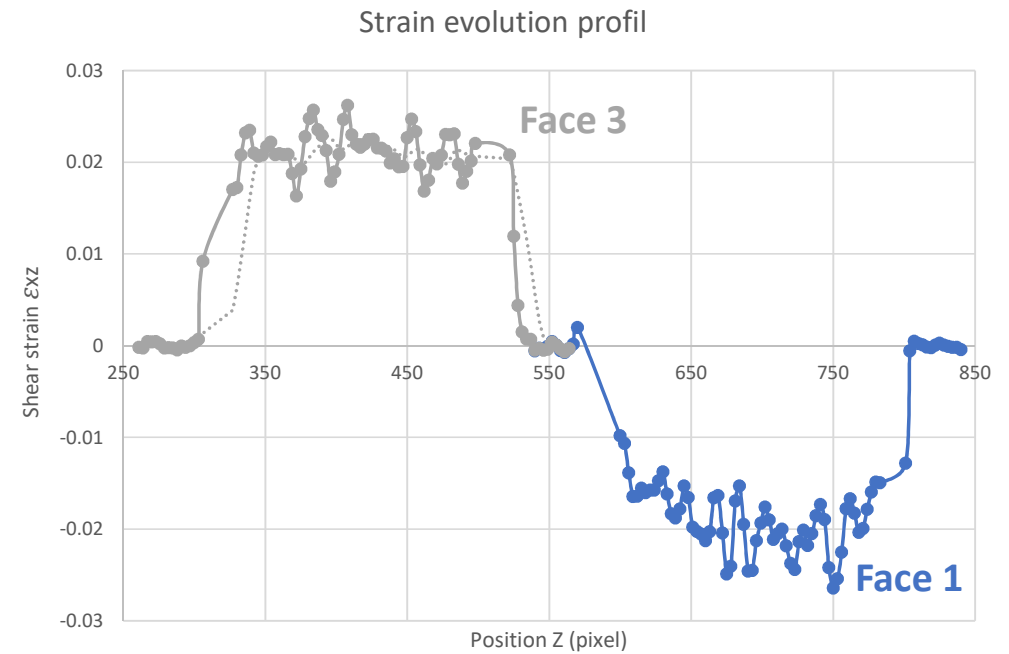
Mechanical shear behavior PVC80 - 4 faces



3. Experimental part

→ Shear test : (\vec{x}, \vec{z}) plan

	G MPa	R : Shear strength MPa
PVC 1	24,35	1,72
PVC 2	28,3	1,55
PVC 3	28,48	1,54



Datasheet : Airex C70 characteristics

Valeurs typiques pour AIREX® C70		Unité (métrique)	Valeurs ¹⁾	C70.40	C70.48	C70.55	C70.75	C70.90	C70.130
Densité nominale	ISO 845	kg/m ³	Moyenne Domaine typ.	40	48 43 - 55	60 54 - 69	80 72 - 92	100 90 - 115	130 120 - 150
Résistance au cisaillement	ISO 1922	N/mm ²	Moyenne Minimum	0.45	0.55 0.50	0.85 0.70	1.2 1.0	1.7 1.4	2.4 2.1
Module de cisaillement	ASTM C393	N/mm ²	Moyenne Minimum	13	16 14	22 18	30 24	40 34	54 45

⇒ No need for FEMU

4. Numerical part

→ Compression tests (3 different slenderness ratios)

5 parameters



$(E_y, E_z, \nu_{yx}, \nu_{yz}, G_{xz})_{app.}$



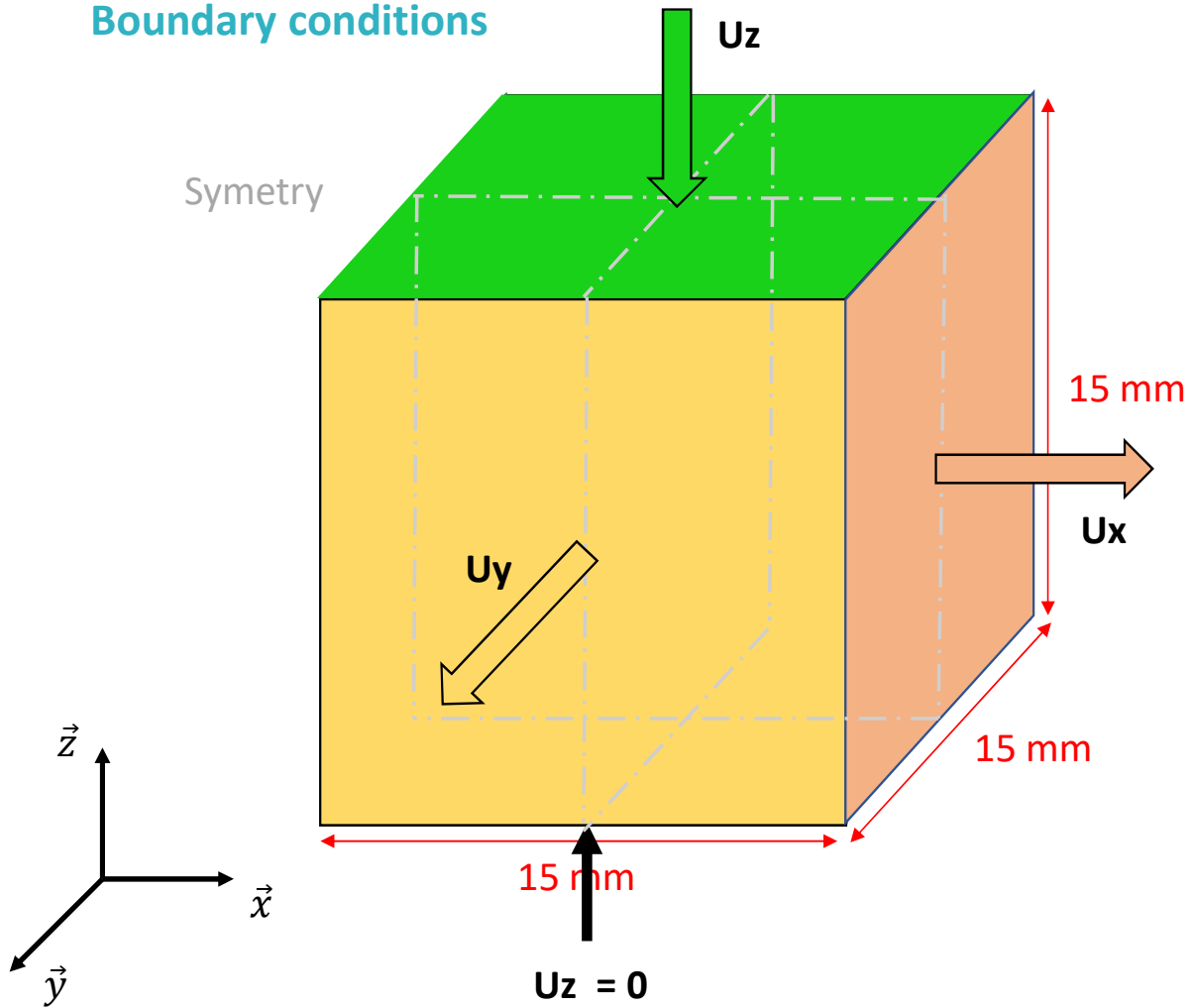
Finite Element Model Updating
(FEMU) method

5 parameters

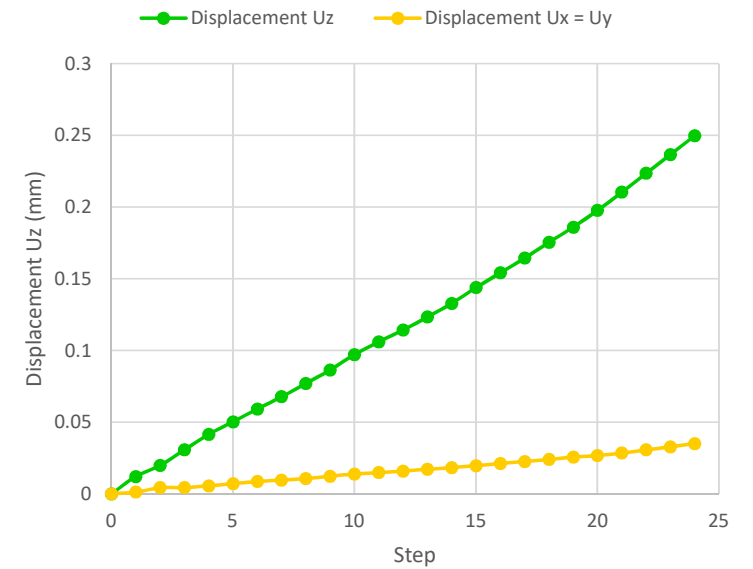
$(E_y, E_z, \nu_{yx}, \nu_{yz}, G_{xz})_{int.}$

4. Numerical part

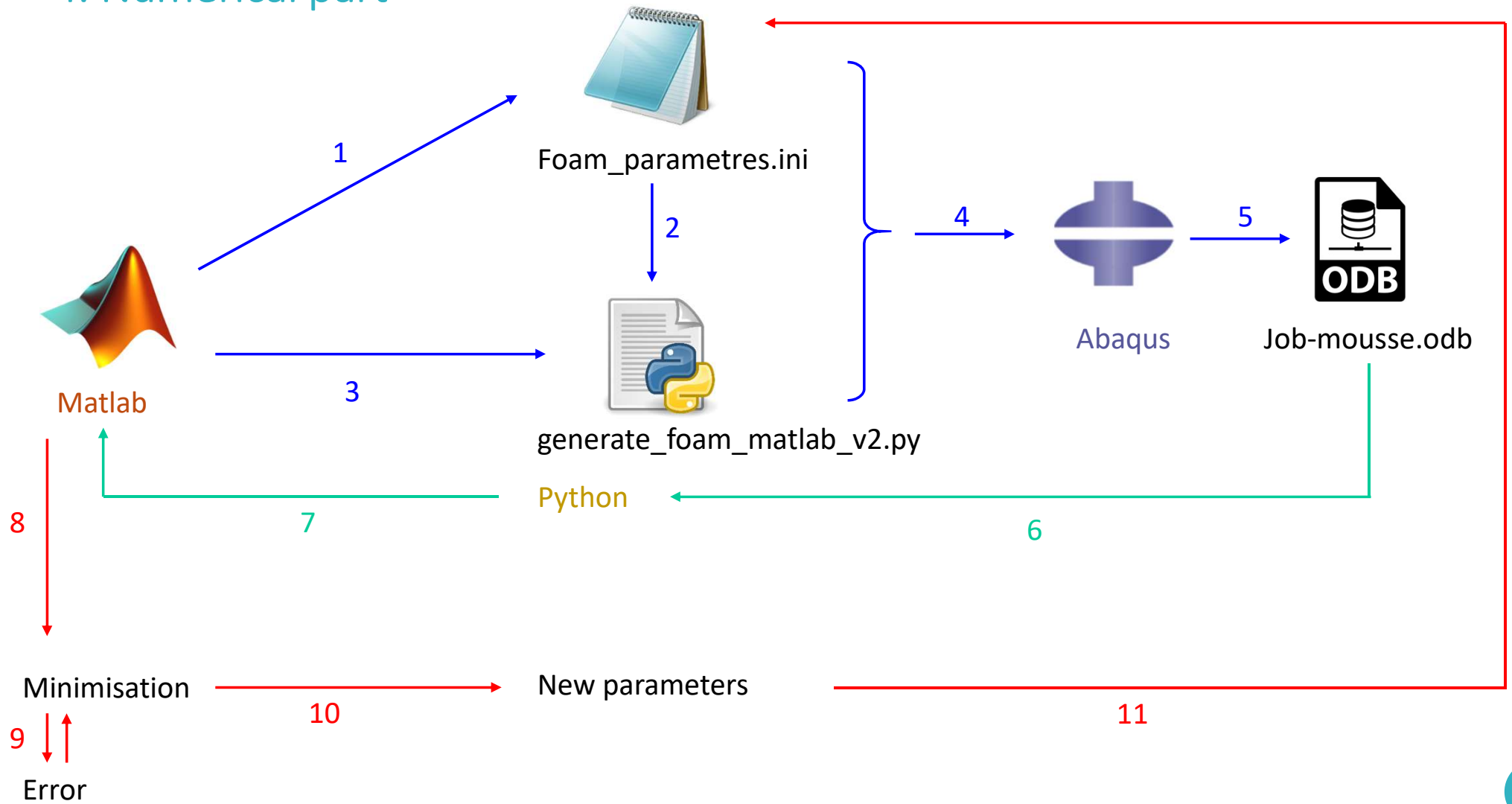
Boundary conditions



Boundary conditions for PVC80 – 15x15

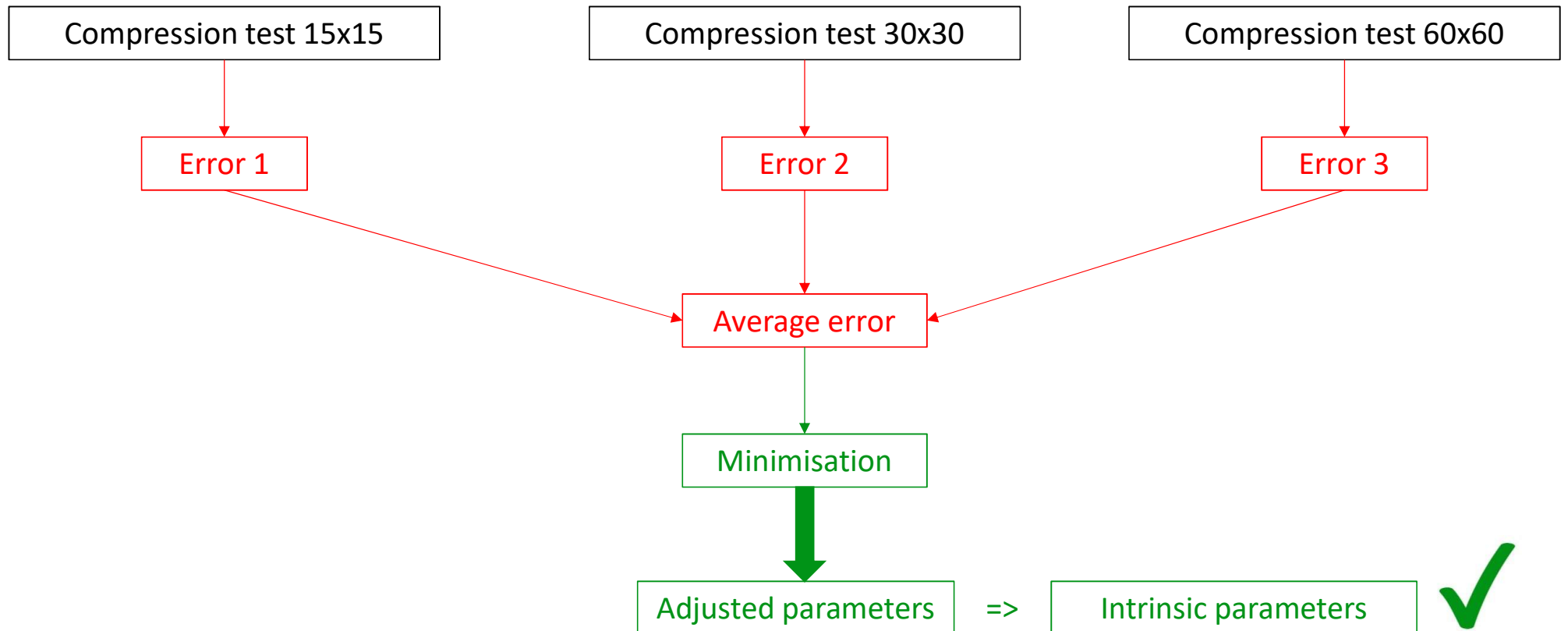


4. Numerical part

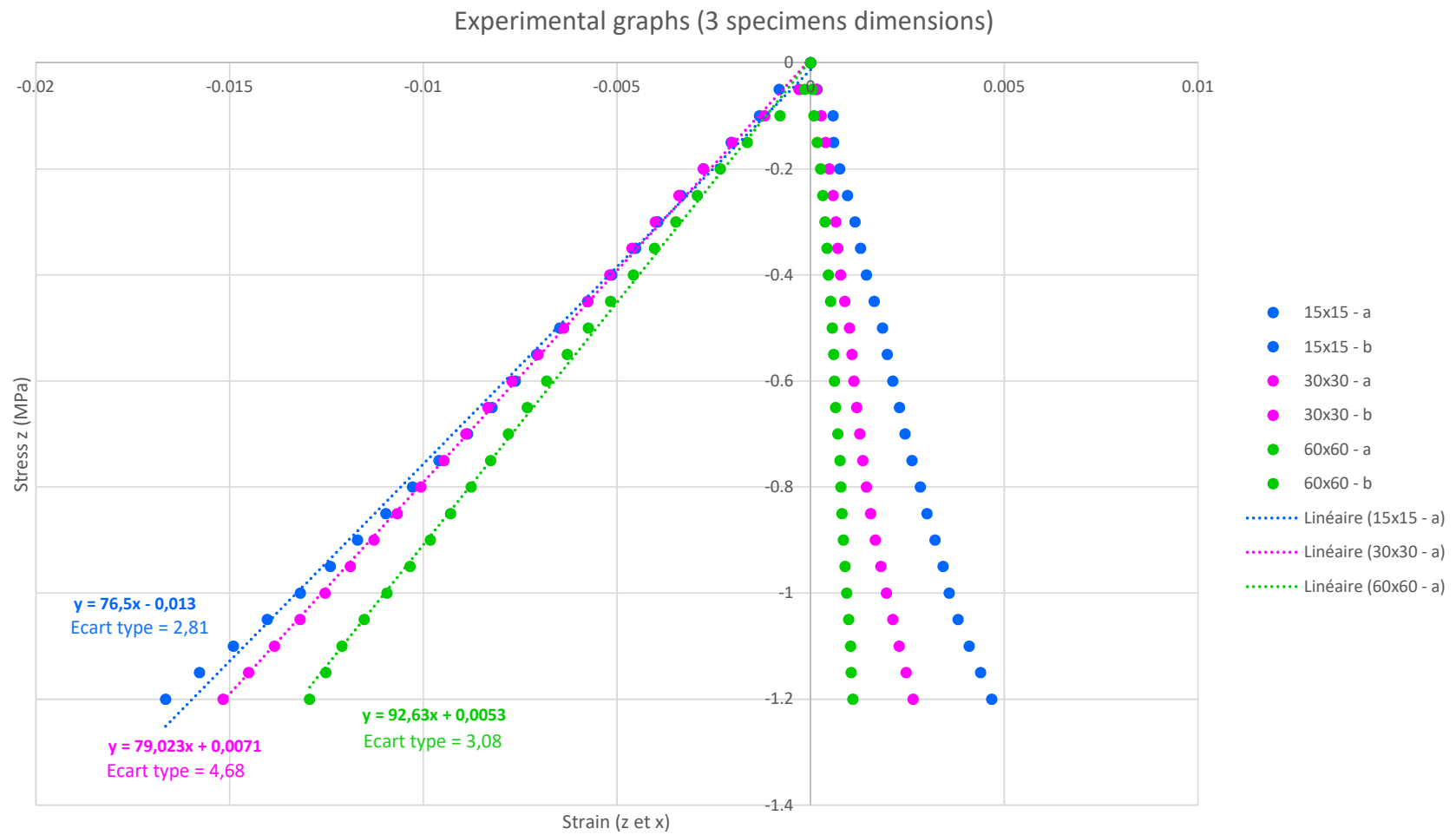


4. Numerical part

Calibration of the 3 compression tests (in parallel for 3 dimensions)



4. Numerical part

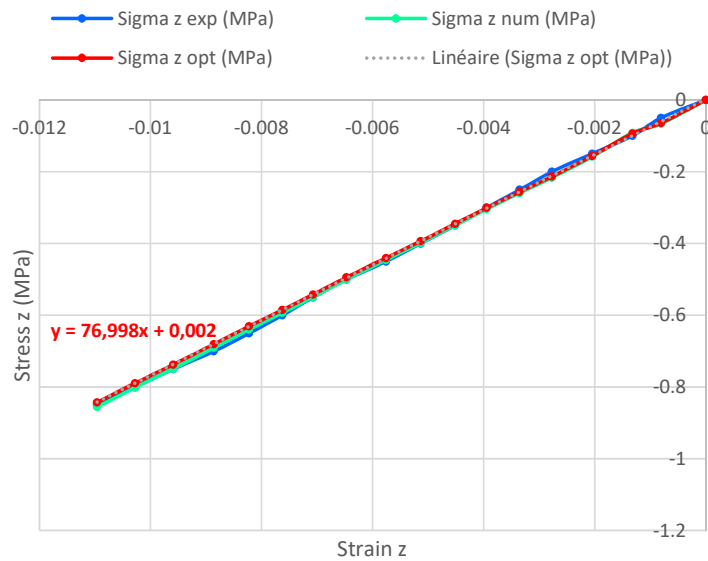


4. Numerical part

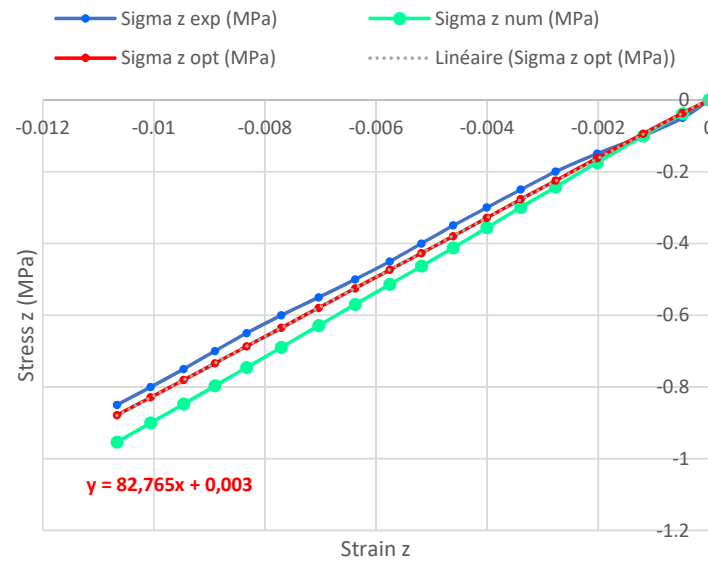
Results

	Ex	Ey	Ez	vxy	vxz	vyz	Gxy	Gxz	Gyz
Adjusted values	= Ey	43,71 MPa	77,58 MPa	0,34	= vyz	0,144	= $\frac{Ex}{2*(1+vxy)}$ = 16.31 MPa	30 MPa	= Gxz

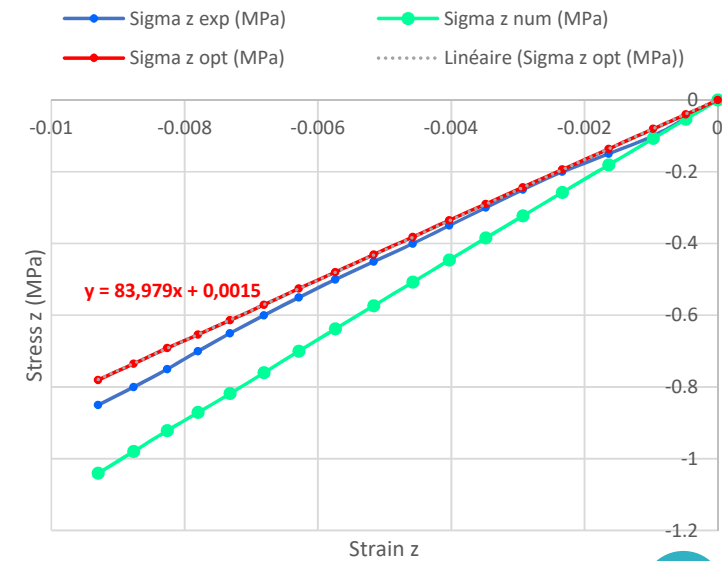
PVC 80 15x15



PVC 80 30x30



PVC 80 60x60



5. Conclusion & perspectives

- Validation of transverse isotropy theory
 - Obtaining the five elastic coefficients (compliance matrix)
 - FEMU method => intrinsic elastic behavior of the foam
-
- Establishment of a statistical morphological model of the foam (tomography, SEM, Pycnometry ...) and its homogenized behavior
 - Studying the effect of resin impregnation in the homogenized behavior
 - Prediction of the homogenized behavior of monolithic and sandwich composite