Elastic characterization of a poro-elastic layer in a sandwich structure

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Industrial problems:

- **Reduction** of vehicle’s **pass-by noise** in Europe

**Solutions: Acoustic shield system**

- Engine hood
- Heat cover
- Mud flap shield
- Underfloor shield

-6 dB of engine noise
• Manufacturing process: **thermo-compression**

  - uniform layer
  - compressed at 210°C
  - molded part

• Automotive Hood liner: **thickness map**

  - How to model
  - Vibro-acoustic response of a **sandwich structures** with local material’s properties?

  Predicted **material’s properties** from their non-compressed **original value** and the **compression rate** n
Effect of compression on material’s properties
Non-acoustical parameters

• Definition of compression rate $n$

\[ n = \frac{h^{(1)}}{h^{(n)}} \]

• Non-acoustical parameters (JCAL model) vs compression rate (ref [1,2])

\[(\phi, \sigma, \alpha_\infty, \Lambda, \Lambda', k_0')\]


Measurements method for the elastics parameters

- **Classic method:** Quasi-static mechanical characterization of *poro-elastic* materials [1]

  Characterized properties:

  \[ E_L \text{ – Longitudinal Young’s modulus} \]
  \[ \nu \text{ – Poisson’s ratio} \]
  \[ \eta \text{ – damping loss factor} \]

- **In-situ method:** inverse identification from the *velocity /force FRFs* of *sandwich structure* with a *porous core*

  Characterized properties:

  \[ G \text{ – shear moduli} \]

Objectives

Effect of the compression on elastic properties

- Longitudinal Young’s modulus
- In-plane Shear moduli
Longitudinal Young's modulus

- Young's modulus for an isotropic material is estimated from the dynamic stiffness:
  \[ E = \frac{k \cdot L}{S} f(\nu), \quad \nu = 0, f(\nu) = 1 \text{ for the fibrous material} \]

Preload: \( m = 42.36 \text{ g for fibrous material} \) (<50 Pa for foam)
Excitation amplitude: < 0.1% static deformation
Longitudinal Young’s modulus vs compression

\[ E_L^{(n)} = E_L^{(1)} \times n^{(2.87)} \]

A power law for Longitudinal Young’s modulus
In-plane Shear moduli

- Manufactured sandwich plates (Aluminum + glass wool + Aluminum)

Plate thicknesses: 13 mm, 10 mm, 7 mm
210°C compressed for 5 min

Aluminum thickness: 0.1 mm

Dimensions
Lx = 42.7 cm, Ly = 12 cm,
Lz = 0.7 cm, 1 cm, 13 cm

Flexural behavior driven by the shear moduli
• Inverse characterization method:

- Measurements
- Numerical Model

Best fitting over the frequencies and the modes shapes

Estimated parameters $G_{13}, G_{23}$

Preliminary parametric studies
Measurements of the FRFs (Velocity/Force)

The plate is **suspended** with two strings and excited by a shaker.

The **quadratic normal velocity** is measured by a scanning laser vibrometer over **190 points**.

**Linear behavior at low excitation**
Overview of the ZPST element (ref [3]):

- shell element
- multilayered element (elastic and poro-elastic layers)
- polynomial interpolation and a zigzag function in the thickness

• For elastic layers:

\[ \int_V \delta \varepsilon : \sigma + \rho \delta u \frac{\partial^2 u}{\partial t^2} \, dV - \int_S (\sigma \cdot n) \delta u \, dS = 0 \]

• For poro-elastic layers \((u, p_f)\):

\[
\nabla \sigma^s + \omega^2 \tilde{\rho} u = -\tilde{\gamma} \nabla p_f ,
\]

\[
\Delta p_f + \omega^2 \frac{\rho_{22}}{R} p_f = \omega^2 \tilde{\gamma} \tilde{\rho}_{22} \phi^2 \nabla u .
\]

with orthotropic stress-strain relation:

\[ \sigma_{ij}^s = C_{ijkl} \varepsilon_{kl}^s \text{ and } C_{ijkl} \text{ with 9 elastic parameters } (E_1, E_2, E_3, \nu_{12}, \nu_{13}, \nu_{23}, G_{12}, G_{13}, G_{23}) \]

• Coupling conditions:

\[ \sigma_1^t \cdot n = \sigma_2^t \cdot n, \]

\[ u_1 = u_2, \]

\[ U_2 \cdot n - u_2 \cdot n = 0. \]

Mesh:
- 40 elements, **1425 DOFS**
- Quadratic quadrangles Q8
- Order of interpolation (p=2) for the displacement and pressure approximations

**Calculation times:**
- **3.5 second per calculation** 50 – 350Hz
Results
Sandwich plate 7 mm

Estimated Parameters: $G_{13} = 1.55$ MPa $G_{23} = 3.28$ MPa
Results
Sandwich plate 7 mm

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Results
Sandwich plate 10 mm

Estimated Parameters: $G_{13} = 0.4 \text{ MPa}, \ G_{23} = 2.5 \text{ MPa}$
Results
Sandwich plate 13 mm

Estimated Parameters: $G_{13} = 0.65 \text{ Mpa}, G_{23} = 2.1 \text{ MPa}$
Target thickness: 12 mm, 10 mm, 8 mm

Compressed thickness: 13 mm, 7 mm, 10 mm
In-plane shear moduli vs compression

No clear tendency for shear moduli due to polymerization effect.
Conclusions and perspectives

Conclusions:

• The longitudinal Young’s modulus varies as function of the compression rate by a power law
• The proposed inverse characterization gives a fast and good estimation of the shear moduli
• Nominal values with uncertainty ranges are necessary to take into account the variability
• The polymerization level of the binder plays an important role on the mechanical behavior

Perspectives:

• Parametric study of the polymerization and the compression effect to the mechanical properties of a sandwich plate with a porous core
Thank you for your attention!

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Variability on 2 samples
13 mm