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PVB mechanical constants characterization in laminated glasses using low frequency ultrasound

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To predict the behavior of a partition made of laminated glasses, it’s necessary to know the parameters of the layers composing it. These types of devices are composed by monolithic glass and an intermediate muffling layer usually made of PVB. In this study, we present a method to find the mechanical constants of PVB in laminated glasses. Mechanical constants characterization in these materials is studied using a model-based inverse problem and the data obtained from an ultrasonic transmission setup: a numerical simulation of the system is proposed using a lineal finite elements model of the ultrasonic propagation on the multilayered solid. Parameters are obtained by minimizing divergences between experimental and numerically predicted waveform.

1 Introduction

The need for precise predictions of acoustic isolation is increasingly growing due to the application of current regulations, focused on guaranteeing a certain comfort (or health) level for final users. This implies serious difficulties, mainly because experimental data obtained from laboratory measurements (standardized transmission chamber) deviate from on site measurements, due to contributions from indirect propagation and particular boundary conditions. The relatively large uncertainty of on site measurements has to be taken into account as well.

We are interested in partitions formed by several layers:

a) Monolithic glass, with standardised characteristics, which acoustically behaves as a impermeable layer.

b) Polymeric films, usually PVB (Polyvinyl Butiral), with organic components, or PMMA (PolyMetyl MetAcrilate), which derive from metacrilate resins. From an acoustic point of view, both of them attenuate vibration transmission (damping).

It should be noted that glass thickness is significantly larger than that of intermediate polymeric films, and that a large number of configurations include a three-layer structure with two glass panels of the same thickness (symmetric laminate).

ISO/PAS 16940:2004(E) [2], describes a method for the measurement of the loss factor and the equivalent bending rigidity modulus of laminated glass test pieces. The aim is to compare the properties of interlayers. These two parameters (and others such as density and thicknesses of glass components) can be related to the sound transmission loss (STL) of the glazing itself. provides with a method for the calculation of transmission losses in this kind of partitions. So, TL=10log(1/τ(θ)) and:

$$\tau(\theta)=\frac{I_{tx}}{I_{inc}}=\left\{\left[1+\eta\cdot\left(\frac{\omega\cdot\rho_s}{2\cdot\rho\cdot c}\cdot\cos(\theta)\right)\cdot\left(\frac{\omega^2\cdot B}{c^4\cdot\rho_s}\cdot\sin^4(\theta)\right)\right]^2+\left[\left(\frac{\omega\cdot\rho_s}{2\cdot\rho\cdot c}\cdot\cos(\theta)\right)\cdot\left(1-\frac{\omega^2\cdot B}{c^4\cdot\rho_s}\cdot\sin^4(\theta)\right)\right]^2\right\}^{-1} \quad (1)$$

Where I is the sound intensity (W/m2), ρs the surface density of the plate (kg/m2), and the rest of the parameters have been previously defined. The standard also includes an experimental procedure which permits to obtain the equivalent stiffness modulus of a laminated glass, dependent on the frequency B=B(fi) and the loss factor of the whole system. In order to obtain the diffuse field transmission coefficient, the standard proposes a limit angle of 75º.

However, this standardized expression has less utility (and a lower quality) as predictive model than the models based on impedance coupling, such as RKU model (Ross-Kerwin-Ungar, 1959 [7]) analysis or Ookura-Saito, 1978 [3]).

The uncertainty in the determination of transmission loss (TL) of sandwich panel-like structures - laminated glass- is partly due to the uncertainties on the vibrational and mechanical properties of their components coming from the fact that, in particular, polymeric films do not co-exist with identical properties independently from the multilayer structure. Essentially, the parameters defining acoustic behaviour are bending stiffness and loss factor.

By the other hand, ASTM/C 623–92 [9]describes a method covers the determination of the elastic properties of glass and glass-ceramic materials. Specimens of these materials possess specific mechanical resonance frequencies which are defined by the elastic moduli, density, and geometry of the test specimen. Therefore the elastic properties of a material can be computed if the geometry, density, and mechanical resonance frequencies of a suitable test specimen of that material can be measured. Young’s modulus is determined using the resonance frequency in the flexural mode of vibration. The shear modulus, or modulus of rigidity, is found using torsional resonance vibrations. Young’s modulus andºshear modulus are used to compute Poisson’s ratio, the factorºof lateral contraction. All glass and glass-ceramic materials that are elastic, homogeneous, and isotropic may be tested by this test method. The test method is not satisfactory for specimens that have cracks or voids that represent inhomogeneities in the material; neither is it satisfactory when these materials cannot be prepared in a suitable geometry.

ATSM/ E 758 – 98 [8]covers the description of method measures the vibration-damping properties of materials: the loss factor, h, and Young’s modulus, *E*, or the shear odulus, *G*. Accurate over a frequency range of 50 to 5000 Hz and over the useful temperature range of the material, this method is useful in testing materials that have application in structural vibration, building acoustics, and the control of audible noise. Such materials include metals, enamels, ceramics, rubbers, plastics, reinforced epoxy matrices, and woods that can be formed to cantilever beam test specimen configurations.

An ultrasonic testing revision is made in [1] and it is propossed a method for mechanical constants characterization using a model-based inverse problem and the data obtained from an ultrasonic transmission setup: a numerical simulation of the system is proposed using a lineal finite elements model of the ultrasonic propagation on the multilayered solid. Parameters are obtained by minimizing divergences between experimental and numerically predicted waveform. This is that we takes as starting point and we applied to particular multilayered partitions: the laminated glasses. A first calibration is made with the monolithic

In ultrasonic conventional characterization methods like the pulse echo method, the pulse transference method and the resonance testing methods are avoided for characterization of thin layers, whose thickness are comparable or smaller than the wavelength. Although high frequency ultrasonic waves can be used, they are also averted due to high attenuation of the travelling wave. Taking care of these difficulties, a low frequency ultrasonic transmission test is proposed in which a wave is transmitted through the layered sub-wavelength specimen and recorded; numerical simulation of the system is done by using a linear FEM model. The mechanical constants (thickness, elastic modulus, Poisson ratio, density and attenuation) of the different layers are identified by minimizing the discrepancy between the real and numerically predicted waveform which is done by regularly updating the FEM model throughout the iterative algorithm.

A feasibility study of the method described in [1] is undertaken at lower frequencies and for a very specific sandwich: the laminated glass.

The test method measures the resonance frequencies of test bars of suitable geometry by exciting them at continuously variable frequencies. Mechanical excitation of the specimen is provided through use of a transducer that transforms an initial electrical signal into a mechanical vibration. Another transducer senses the resulting mechanical vibrations of the specimen and transforms them into an electrical signal that can be displayed on the screen of an oscilloscope or an analyzer to detect resonances. The resonance frequencies, the dimensions, and the mass of the specimen are used to calculate Young’s modulus and the shear modulus. The loss factor and the equivalent bending rigidity modulus are determined from the measurement of the mechanical impedance of the glass beam sample.

Resonance frequencies for a given specimen are functions of the bar dimensions as well as its density and modulus; therefore, dimension should be selected with this relationship in mind. When the transfer function corresponding to the input impedance is measured, resonance frequencies fres,i. are determined .The loss factor is then calculated using the relationship resonance.

The configuration of the cantilever beam test specimen is selected based on the type of damping material to be tested and the damping properties that are desired. Two transducers are utilized. One transducer applies the excitation force, and the other measures the response of the beam.Because it is necessary to minimize all sources of damping except that of the material to be investigated, it is preferable to use transducers of the noncontacting.

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2 Methodology

2.1 Experimental setup

Two types of characterization methods have been implemented: modal analysis and ultrasonic test. Different specimens have been used in this study: monolithic glass of 4, 5, and 6 mm of thickness, and normal laminated glass of 4+4, 5+5 and 6+6, all of them 38 cm length.

Concerning ultrasonic method, test samples were square shaped (30cm×20cm) and the same thickness of previously mentioned. Normal vaseline was used as the interfacial couplant. A transmission setup (using a separate transmitter and receiver) is proposed where the complete waveform is recorded for its inversion in order to find out the elastic constants of the traversed media.

Figure 1. Transmitter and receiver transducers used.

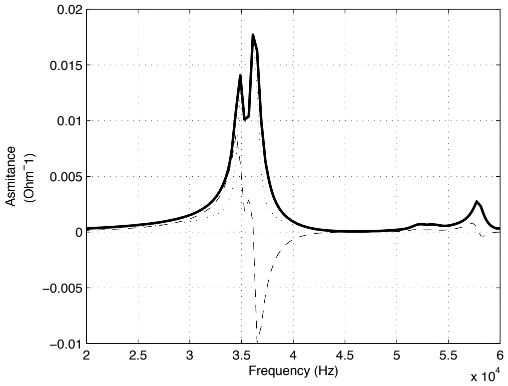

Figure 2. Transducer impedance curve

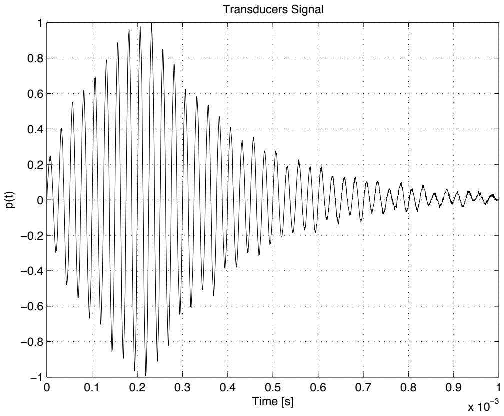

Figure 3. Received signal with transducers in position of figure 1.

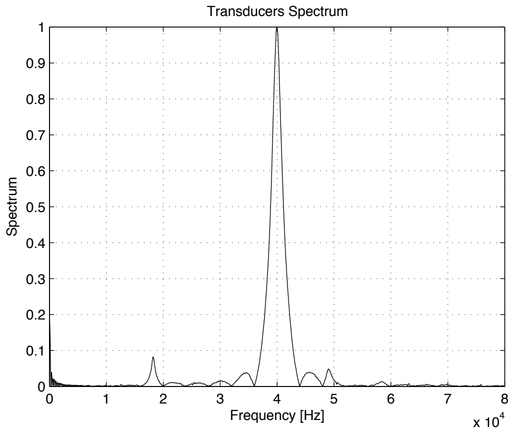

Figure 4. Frequency response corresponding to signal of previous figure.

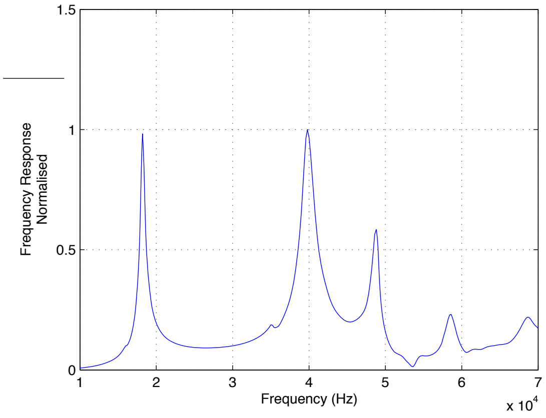

Figure 5. Experimental frequency response measured with an impedance analyzer.

2.2 Numerical simulation

To synthesize recordings, a numerical simulation of the experiment is proposed using a linear FEM model of the ultrasonic propagation of the waves on the multilayered solid that it is composed of. It is constructed using the research academic code in Ansys©.

A 2D plain strain model is assumed, since the 3D effects are expected to be limited, at least for the purpose of this feasibility study. The transmitter is modelled by a prescribed displacement boundary condition by a normal displacement varying only with time which is uniform over the transducer contact area. The receiver is modelled by the integral of the normal pressure fields using a constant weighting function over the transducer contact area. A displacement proportional to the signal is applied at the transmitter interface and received at the receiver interface. The recorded output waveform is compared with the waveform computed by FEM model.

The boundary conditions applied on the model ensures only longitudinal displacements along every degree of freedom, which allows modelling a P-wave front

The mechanical parameters characterization - inverse problem is carried out with an iterative strategy based on the minimization of some discrepancy between the measured and numerically predicted waveforms, $P_m(t)$ and $P_p(t)$ respectively. The discrepancy can defined as a vector of values $D = P_m(t) - P_p(t)$. We can define a cost function

$$C = \frac{1}{2}\int_0^T D^2(t)dt \qquad (2)$$

Within the context of inverse problems the characterization is stated, therefore, as a minimization problem, so finding "x" such that

$$C(x) \quad \min \quad (3)$$

3 Results

3.1 Monolithic Glasses

In figure, we show the mechanical response of monolithic glass of 4, 5 and 6 mm of thickness.

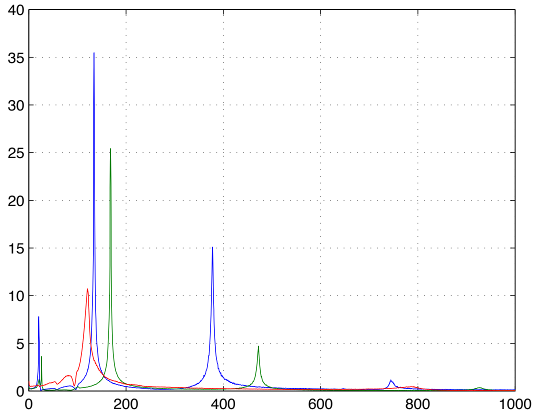

Figure 6: Mechanical response for monolithic glasses of 4, 5 and 6 mm thickness.

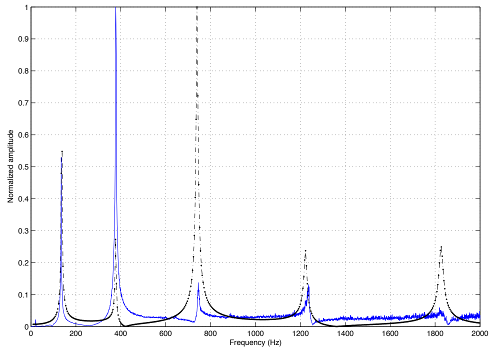

Figure 7. Mechanical response for monolithic glasses of 4mm thickness compared with the theoretical response.

Concerning ultrasonic test, we show only the experimental results for the test sample of 4 mm

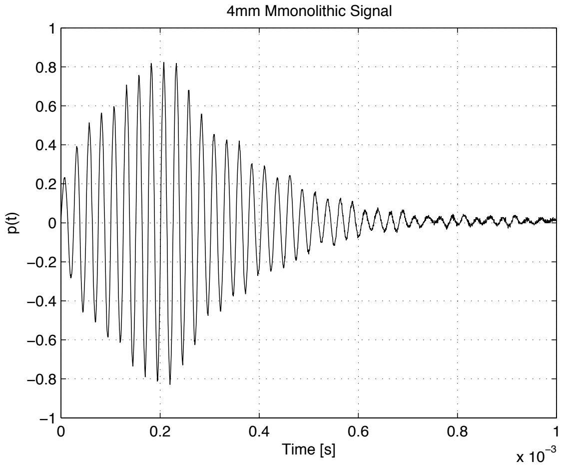

Figure 8. Temporal response when a monolithic glass is placed between both transducers.

3.2 Laminated Glasses

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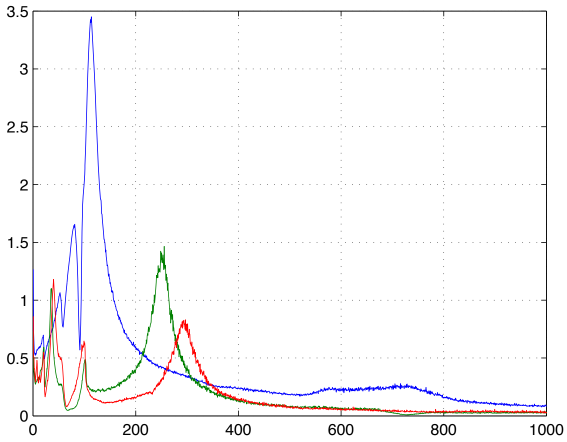

Figure 9. Mechanical response for laminated glasses of 4+4, 5+5 and 6+6 mm thickness.

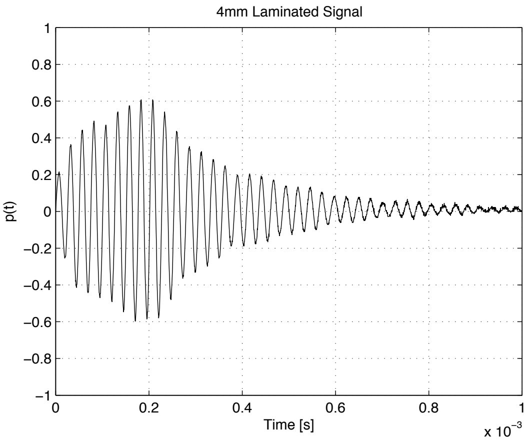

Figure 8. Temporal response when a 4+4mm laminated glass is placed between both transducers.

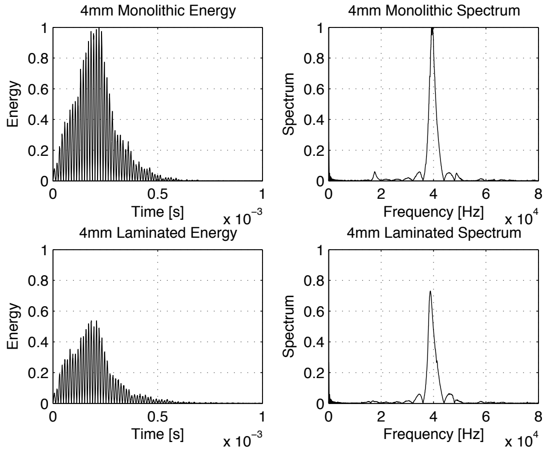

Figure 9. Comparisson of monolithic and laminated energetic and frequencial response.

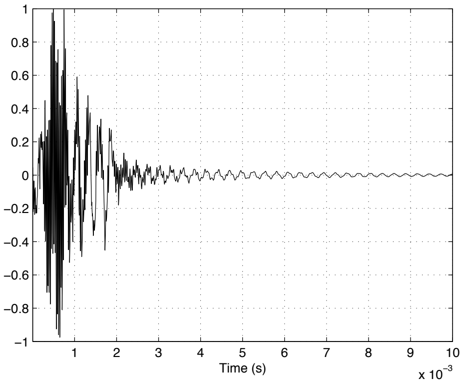

Figure 10. Temporal numerical simulation results in a first attempt.

5 Conclusion

A technique is proposed to determine Bending Stiffness and Loss Factor properties, of multilayered partitions, which involves solving the reconstruction inverse problem based on a FEM model of the ultrasound propagation and using as input data the experimental waveforms obtained from a transmission setup at ultrasonic low frequency. This technique is proved experimentally consistent, but is still limited in that results are sensitive to uncertainties of interfacial couplant, transducer response & transducer coupling with specimen (boundary conditions: free or fixed), as well as a priori information that provides the initial guess.

Acknowledgments

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