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LOSS FACTOR FOR MONOLITHIC AND LAMINATED GLASS

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Abstract

The loss factor and the elastic characteristics are parameters of special relevance for the calculation of the sound insulation of constructive elements. The constructive solutions based on monolithic and laminated glasses are more frequent every day. Therefore, it is of great interest to know the measurement techniques and their limitations with the intention of being able to limit the uncertainties in calculations of the sound insulation. In the laminated glasses takes part several layers of monolithic glasses related with a layer of an organic compound (usually Polibutil-Vinyl (butiral or PVB)) whose nature is crucial in the global behavior of the element. It can be considered as a classic multilayer structure. In this work, the limitations of the experimental techniques that are applied for to determine the loss factor of the different layers are discussed. It is studied for monolithic glasses and for different layers of PVB. In addition, it is carried out a study of the consequences that the uncertainties in the determination of the loss factor cause in the calculation of the sound insulation.

INTRODUCTION

The objective of this work is the study of monolithic and laminate glasses. Glasses with layers of these types:

- Monolithic glasses, whose general characteristics are described in UNE-EN 572-1. These glasses behave, acoustically, like waterproof layers, in which the acoustic wave causes a vibration in the plate and a great amount energy is reflected.

- Damping layer, type PVB (Polibutil-vinyl - Butiral), or PMMA (PoliMetil-MetAcrilato), or another one that attenuates the transmission of the vibration.

A detailed study of the vibrational behavior of a system formed by two equal plates with thin interlayer can be found in reference [10]. In this work a simple model [3] has been used to evaluate the implications that the uncertainty produces in the Transmission Loss predictions when the loss factor is determined.

Outstanding parameters in the Acoustic Behavior of glasses

One of the most important parameters to determine the glass damping is the loss factor, η, that is defined as the quotient of the dissipated energy per radian D, at the angular frequency w_n, and the maximum potential energy W that the system can store in a vibration cycle, according to the expression (1.1). Alternatingly the loss factor can be calculated in the frecuency range from the band width of the half power (1.2):

$$\eta \overset{(1.1)}{=} \frac{D}{2\pi W} \overset{(1.2)}{=} \frac{f_2 - f_1}{f_0} \qquad (1)$$

Where f_0 is the resonance frequency and f_2 and f_1 are, respectively, the half power frequencies for above and below.

Figure 1 shows the superior and inferior limits of the loss factor, as a frequency function, corresponding to several types of intermediate sheets at 20º C [1]. The common PVB reaches a value around 0.4 while those used specifically for acoustic applications vary between 0.8 and 1.2. The two straight line can be adjusted easily with equations of the type:

$$\eta = A + \frac{B}{\sqrt{f}} \qquad (2)$$

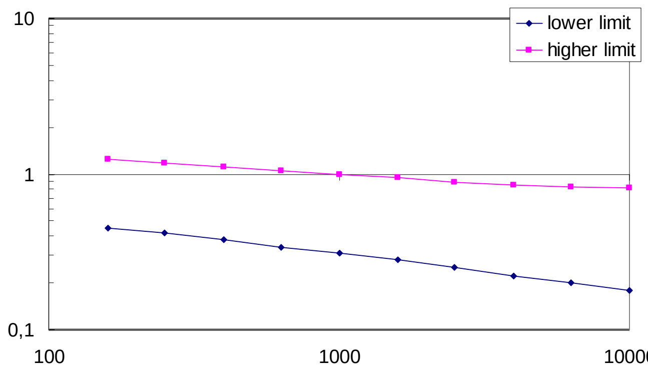

Figure 1

When a glass is subjected to acoustical or mechanical excitation at certain frequency, the speed of propagation of the wave of free bending in the panel is equaled to the speed of the sound in the air; this frequency is defined as critical frequency [3]. With acoustical excitation the vibrational response of a panel is bigger around the critical frequency. The knowledge of this frequency is very useful for designing, since a structure can be constructed so that its critical frequency is outside of the frequency range in which the acoustical excitation is superior when the loss factor reaches its maximum.

On the other hand: Young's modulus of a glass, E, governs the bending and tension phenomena, the shear modulus, G, explains the behavior of the possible slides among layers and the Poisson coefficient , μ, the lateral contraction. It is known that these three parameters are related by means of this expression $G = E/2(\mu - 1)$. Also it is known that for the glasses the critical frequency is determined by the following relationship:

$$f_c = A \cdot c^2 \sqrt{\frac{m}{L \cdot B}} \tag{3}$$

B is the stiffness bending, $B = I \cdot E$; being I the inertia moment of the traverse section of the bar, regarding the 'neuter axis' of this. E is the Young's modulus of the material. L the length of the bar and m the mass of the element. The speed of the sound in the air is c. A is an adimensional factor that includes shape parameters and boundary conditions.

Procedures for Characterization of Monolithic and Laminate Glasses

There are three main normatives used for characterizing these glasses:
- The normative ISO/PAS 16940:2004, that describes a method of measure the loss factor and the stiffness bending modulus of samples of laminated glass [4]. It also provides an equation to obtain the transmission loss in this type of glasses.

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

where, I is the sound intensity (W/m2), η is the composite plate loss factor, (dimensionless), ω is the angular frequency, (rad/s); ρ_s is the plate density surface, kg/m2, ρ is the air density, kg/m3, c is the speed of sound in air, m/s, θ is the angle of incidence and B is the plate stiffness bending per unit width, N·m.

- The normative ASTM/C 623-92, that establishes a dynamic method to determinate the Young's modulus, the shear modulus and the Poisson coefficient [5]. With this geometric data, the density and the resonance frequencies of a sample, the elastic properties of that material are obtained. The Young's modulus is determined from the resonant frequencies of the bending vibration modes. All the elastic, homogeneous and isotropic glasses and glasses-ceramic can be analyzed by this method.

- The normative ASTM/E 756-98, allows to determine the Young's modulus and the shear modulus of elastomeric materials, when the loss factor is known and when the elastomeric material is confined between two rigid sheets deformed to bending [6]. In this document is pointed out that "Extra care should be taken when the modal loss factor of the test specimen exceeds 0.2.... ". We are exactly in this situation. The uncertainty in this case can reach the 50%.

In the three mentioned normatives the procedure consists on exciting mechanically the studied bar to obtain the transfer function (force/velocity) measuring the vibrational response of the system by an accelerometer or any other sensor located at the free end of the bar.

The Ookura & Saito Model [7].

Figure 2 shows a general structure of multiple infinite walls. This structure is designed with N elements and each one of these elements can be a waterproof layer, an air camera or an absorbent material. pi is the pressure of the incident wave and pr the pressure of reflected wave. It is supposed that a plane wave impacts on the left face of the N-element with an incidence angle θ. The wave that impacts on the left part will continue spreading through the structure and it will radiate at the right face of the first element like a plane wave of pressure pt toward a free field with a transmission angle θt. In the analysis each one of the physical parameters of the i-element is numbered with the subindex i=1, 2,..., n, and a second subindex is used to indicate a parameter of the left face of the element (2) and the right face (1), like shows the Figure 2.

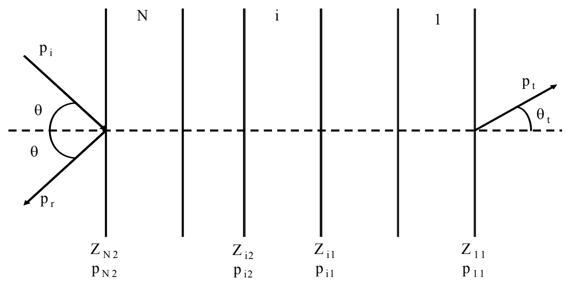

Figure 2

The quotient between the pressure on the incidence surface pN2 and the incident pressure pi is the following one:

(5)

Where Z_{N2} is the acoustic normal impedance from the left face of the surface of the n-element and $\rho c/\cos\theta$ is the acoustic normal impedance in free field of a surface with oblique incidence, which is similar to the impedances relationship of the first element Z_{11}. Using the conditions of pressure in each surface, the expression of the transmission factor for normal incidence is:

$$\frac{p_{N2}}{p_i} = \frac{p_i \mp p_r}{p_i} = \frac{2Z_{N2}}{Z_{N2} + \frac{\rho c}{\cos\theta}}$$

$$\tau(\theta) = \left|\frac{p_t}{p_i}\right|^2 = \left|\frac{p_{11}}{p_i}\right|^2 = \left|\frac{p_{N2}}{p_i}\right|^2 \left|\frac{p_{N1}}{p_{N2}} \cdots \frac{p_{i1}}{p_{i2}} \cdots \frac{p_{11}}{p_{12}}\right|^2 \quad (6)$$

The pressures relationships can be obtained from the impedance characteristics of each surface. To obtain the transmission loss for random incidence, is necessary to average the values until a certain limit angle θl, above which is assumed that the sound is not received.

This angle varies between 70º and 85º. The norm ISO/PAS 16940:2004 specifies that the limit angle for glasses is 75º. An alternative to this formulation based on the limit angle, for glass plates, can be consulted in reference [8].

The pressures relationships can be obtained from the impedance characteristics of each element (damping glasses and sheets), taking into account that the vibrations of an infinite plate of thickness h produces a difference of pressures at both sides of the plate, and the speed on the plate in the direction x: $u = (p_2 - p_1)/Z_m$, where p2 is the sound pressure that impacts on the surface in x = 0, p1 is the pressure that is transmitted in x = h and Zm are the surface impedance of the plate that, in a first approach, is given for:

$$Z_m = \eta\omega m\left(\frac{\omega}{\omega_c}\right)^2 \sin^4\theta + j\omega m\left[1 - \left(\frac{\omega}{\omega_c}\right)^2 \sin^4\theta\right] \quad (7)$$

where ω is the angular frequency of the sound wave, m is the mass per area unit, ωc is the critical angular frequency of the plate and η is the loss factor of the plate.

DEVELOPMENT

Equation (4) provides the reflection factor value to observe the effect that the uncertainty in the determination of the loss factor produces in the predictions of the acoustic isolation. From this equation, supposing that the inaccurate only depends on the uncertainty in the determination of the loss factor and of the stiffness bending modulus, the following expression is obtained:

$$\Delta\tau(\theta)=\left|2\tau(\theta)^2\left[\left(\frac{\omega^3\cos\theta D\sin^4\theta\eta}{2\rho_o c^5}+1\right)\frac{\omega^3\cos\theta D\sin^4\theta}{2\rho_o c^5}\right|\Delta\eta+ \\ +\left\|\left[\left(\frac{\omega^3\cos\theta D\sin^4\theta\eta}{2\rho_o c^5}+1\right)\frac{\omega^3\cos\theta\sin^4\theta\eta}{2\rho_o c^5}+\frac{\omega^2\cos^2\theta(D\omega^2\sin^4\theta-\rho hc^4)\omega^2\sin^4\theta}{(2\rho_o)^2c^{10}}\right]\right\|\Delta D; \quad (8)$$

If only the contribution of the loss factor is considered, for an angle of 45º, that is usually considered like approximate reference of the value that would be obtained for diffuse field, the following expression is obtained:

$$\Delta\tau(45^o)=\left|2\tau(45^o)^2\left(\frac{\omega^3D\eta}{2\rho_o c^5}\left(\frac{1}{\sqrt{2}}\right)^5+1\right)\frac{\omega^3}{2\rho_o c^5}\left(\frac{1}{\sqrt{2}}\right)^5\right|\Delta\eta; \quad (9)$$

Figure 3 shows the effect of the uncertainty of the loss factor in the prediction of the transmission for monolithic glasses of 6 mm of thickness.

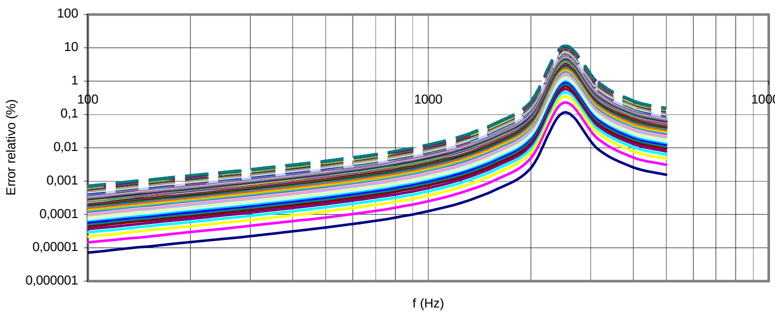

Figure 3

In Figure 4 the influence in the prediction of the acoustic isolation for the case of a monolithic glass of 6 mm is shown.

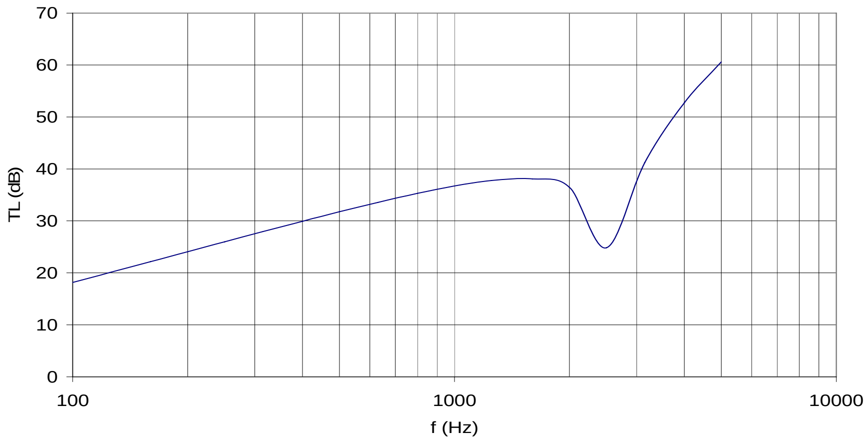

Figure 4

For laminated glasses, using the Ookura & Saito model, a software has been implemented to determine the Transmission Loss and to evaluate the influence of the inaccurate in the value of the loss factor in the prediction of the Transmission Loss for a laminated glasses (4+4) with PVB, and it has been represented in the Figure 5. The graphs show that the effect is notably visible in the critical frequency proximities.

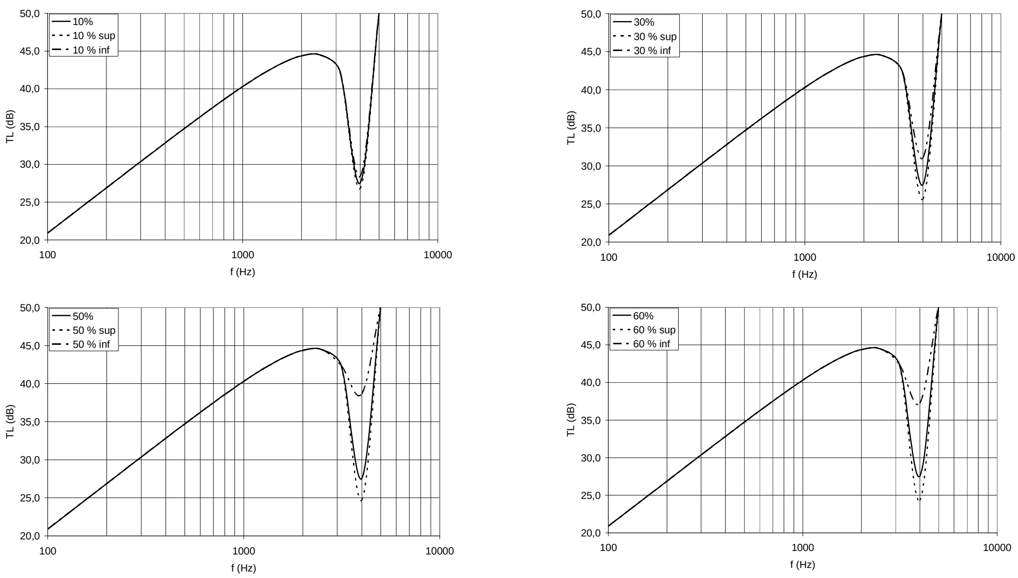

Figure 5.- Límites en la ucertainty of the predicted STL for the Ookura&Sairo Model (4+4 laminated glass)

SUMMARY

To predict the effect that the inaccurate in the determination of Loss factor in the

determination of Transmission Loss of partitions multilayer, a simple model has been used. It can be observed that this effect is more important in the proximities of the critical frequency.
This source of uncertainty can be considered worthless if it is compared with the dispersion of the measured results in different laboratories like those that are shown in reference [9].

ACKNOWLEDGMENTS

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