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On the determination of the modulus of elasticity of plasterboard plates

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HIGHLIGHTS

- Study of standard ISO 16940 and alternative methods for determining the Young's modulus.
- Determination of the modulus of elasticity by mobility resonances instead of anti-resonances allows increasing accuracy.
- Simpler method that allows the better accuracy and uncertainty than ISO 16940.

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ABSTRACT

The importance of an accurate determination of the modulus of elasticity has increased with the development, characterization and manufacturing processes of more complex materials as plasterboards or layered materials. This fact has led to the need of methods beyond the classical stress-strain slope. Several standards can be found describing such procedures in order to determine the Young's modulus. This work presents an analysis of different methods, including the standard ISO 16940. Several of the methods presented are based on the response of the system to a harmonic force as this standard, but this work also presents a method based on the free response of the tested sample to an initial loading condition. This method involves a significant reduction of the experimental procedure and equipment investment. The methods formulation is presented and illustrated with a numerical case based on a finite element model. The methods presented are also used on an actual case: the determination of the modulus of elasticity of a plasterboard. From both cases, conclusions on the accuracy and precision of the methods are stated.

1. Introduction

Sound transmission of plain building elements depends, among other things, on its bending stiffness, which, in turn, depends on the Young's modulus (or modulus of elasticity). Traditionally, general tabulated values of this last parameter have been used for ordinary building materials such as brick, concrete, plasterboard or glass.

An accurate characterization of the elastic properties of these materials is increasingly important due to the necessity to develop materials that are stronger, stiffer, lighter and even more resistant to extreme environmental conditions in order to assure their performances as well as to guide further developments. This is the case for new products like laminated glasses or some types of plasterboard plates. Nowadays, the use of plasterboards for both structural and nonstructural elements in buildings construction has been increased since the properties of these materials, particularly the gypsum, can be modified to meet specific requirements such as impact, fire or humidity resistance [1,2].

A significant effort has been made in the last years to improve specific characteristics, as thermal storage by means of incorporating phase change materials to the plasterboards [3], or mechanical properties using reinforcement materials as fibres of different materials [4,1] (glass, carbon, polypropylene and expanded vermiculite, between others).

The accurate determination of the mechanical properties (i.e, Young's modulus or tensile/compressive strength) of the plasterboards plays a key role in the whole performance of the structure or building, as well as in the previous mechanical studies. For example, numerical models [5] of building components which include plasterboard elements require the definition of plasterboards properties with a confidence level good enough. In addition, their mechanical properties also influence the acoustic performance and modelling of plasterboard components [6] such as internal partitions.

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For plasterboards, there are procedures for determining their mechanical properties [7,8] or particular performances [9] that concern both the plasterboard panels [1] or partitions [10,11]. Nevertheless, very limited studies are available in literature for these type of materials, despite their increasing importance in different areas of civil engineering. Some test procedures are included in references [3,12], however a lack of comprehensive test campaign on plasterboards in the current literature is noted. Numerical studies that are currently available employ values resulting from a small number of tests and the uncertainty related to this material is not usually taken into account.

Significant advances have been made recently in the use of computer techniques to model new products manufacturing processes. The continuous development of methods to asses the elastic parameters denotes an actual effort to consider the mechanical behaviour of these materials [13,14]. Traditional static procedures for the determination of the modulus of elasticity [15] require specific equipment not usually found in acoustic laboratories. These methods are based on direct measurements of stresses and strains during mechanical tests, and Young's moduli are determined from the slope of the linear region of the stress-strain curve. These techniques suffer from certain disadvantages, they are time consuming, expensive (because of their destructive nature) and considerable sample preparation is required [16,2].

On the other hand, the dynamical methods have the advantage of being non-destructive in nature, presenting an ease specimen preparation and being able to be often performed more rapidly, particularly with the availability of modern electronic test equipment. Nevertheless, they usually require sample sizes not big enough to be representative of the bulk building materials. In the last decade progress on digital processing has allowed developing dynamical procedures based on the flexural response of the specimen.

As stated above, for acoustical applications, the Young's modulus arises in the equation of the flexural stiffness modulus that, in turn, is a key quantity to determine the critical frequency by which the profile of the sound insulation curve of building elements is strongly influenced [17,18]. It also appears, for instance, in the equations of the vibration reduction indices of some types of wall junctions [19]. Thus, in the last decade, there have been published some measurement standards that, specifically, include guidelines for the determination of this quantity for building elements, as in [20] or [21, Appendix F]. In particular, for non isotropic materials as plasterboards, these standards establish also a procedure based on the average of the modulus of elasticity for several samples obtained in the longitudinal and transversal directions of a plate, thus obtaining an equivalent single value.

The aim of these standards is to determine the modulus of elasticity analysing the response of the system in the same location where a harmonic force is applied to the sample. Such response can be studied in terms of mobility (vibration velocity divided by force) or its inverse, the impedance (force divided by vibration velocity). The characteristic values of such responses are their maximum and minimum values that can be theoretically related to the modulus of elasticity and so be used to its determination.

The terms resonance and anti-resonance frequencies are usually used to name the mobility maxima and minima respectively, as it will be used in this work. Nevertheless, it is worth to highlight that mobility resonances are the impedance anti-resonances and that the mobility anti-resonances are the impedance resonances.

The purpose of this study is to present a discussion about different methods for dynamic elastic properties determination of plasterboard elements taking as a reference the one included in [20] (together with [21]) emphasizing aspects such as its accuracy, simplicity, or equipment needed. The study is based on the determination of the modulus of elasticity from two different sources: fundamental bending resonances or anti-resonances of the response to a harmonic excitation and the free response to an initial loading condition.

Section 2 describes the fundamentals of the methods presented along with a description of [20]. A numerical application is studied in Section 3 to show the differences between the methods in terms of accuracy and precision. In Section 4 an experimental application with plasterboard specimens is considered. The conclusions from the work are summarised in Section 5.

2. Methods

This section presents several methods for the determination of the bending modulus of materials. First, the ISO 16940 standard is summarised as this is one of the methodologies more widely accepted for the determination of the bending modulus. Later, three alternative methods are presented: two of them are based on the stationary response of a sample to a harmonic force (the same type of response studied in the ISO 16940) and the last one is based on the free response of the specimen.

2.1. The ISO 16940 procedure

The specific aim of the ISO 16940 standard is the determination of the loss factor and bending stiffness modulus of glass beams. In laminated glass the interlayer plays a main role in the mechanical properties of the glazing and, as a consequence, in its acoustic properties. This way different interlayers can be compared, enabling the development of glazings with better sound insulation performances.

Bending stiffness determination is based on the impedance response of a free-free beam excited by a driven force in its midpoint, where the vibration velocity is also measured. The standard establishes a relationship between each impedance resonance frequency $f_{a_i}^{ISO}$ and the bending stiffness as

$$f_{a_i}^{ISO} = \frac{\left(\lambda_{a_i}^{ISO}\right)^2}{2\pi}\sqrt{\frac{EI}{m(L/2)^4}} \qquad i = 1,2,3\ldots \tag{1}$$

where E is the modulus of elasticity, I is the area moment of the cross-section about the neutral axis, m is the mass per unit length and $\lambda_{a_i}^{ISO}$ is a parameter whose values are listed in Table 1.

Solving for E_i:

$$E_i = \frac{m}{I}\left(\frac{2\pi(L/2)^2}{\left(\lambda_{a_i}^{ISO}\right)^2} f_{a_i}^{ISO}\right)^2 \tag{2}$$

The standard recommends using the first three resonance frequencies to obtain a mean E value.

The values of parameter $\lambda_{a_i}^{ISO}$ shown in Table 1 come from an assumption in the standard that establishes that the vibration modes of the sample loaded in its middle point correspond to the bending modes of two "clamped-free" half length beams. Therefore it is established in the standard that impedance resonance frequencies—the mobility anti-resonances—of the free-free

Table 1
Values of the parameter $\lambda_{a_i}^{ISO}$.

i	$\lambda_{a_i}^{ISO}$
1	1.87510
2	4.69410
3	7.85476
4	10.99554