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An identification method for frequency dependent material properties of viscoelastic sandwich structures

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ABSTRACT

In this paper, an inverse identification method of the viscoelastic material properties (shear modulus G_0 and loss factor η_C) of a symmetric three layered viscoelastic sandwich beam is proposed. Experimental vibration tests are performed to determine resonant frequencies and loss factors for different bending modes. The inverse approach consists into an iterative procedure that determines the mode shapes given the material parameters and then computes the viscoelastic properties from the modes using a Rayleigh quotient until convergence on the material properties is met. As a result, the frequency dependent viscoelastic material properties of sandwich beams are determined in an automated fashion. The method is successfully compared to the Ross-Kerwin-Ungar formulas and to a standard optimization approach. A fit of the viscoelastic material properties is performed providing analytical expressions for these quantities over a wide range of frequencies.

1. Introduction

Constrained viscoelastic sandwich structures are largely used to reduce and control noise and vibrations in aerospace and automotive [1–3]. Thanks to their high stiffness and strength to weight ratios, good fatigue properties, good thermal and acoustical insulation and ease of mass production, they are also popular in engineering applications as load-carrying structural members [4,5]. Viscoelastic sandwich structures are usually three layered structures composed by two thin elastic face sheets that sandwich a viscoelastic core. The face sheets material can be fiber-reinforced plastics [6–8], heat-resistant steel [9] or aluminum alloys [10,11] which are bonded to the core with an adhesive. The core keeps the faces separated, stabilizes them and contributes to the flexural stiffness, out-of-plane shear and compressive strength and introduces a structural damping. As the performance of viscoelastic sandwich structures depends on the material properties of the faces and of the core, it is of importance to characterize material core parameters [12]. In the case of homogeneous and isotropic material, only two elastic values are necessary. It has been established in Refs. [13,14] that the pairs (G,K) or (E,K) are the most suitable to measure. Viscoelastic material characterization is generally done through measurements of the uniaxial shear modulus (G) and the compressibility modulus (K).

In the frequency domain, the resonant method and the non-resonance methods like Dynamical Mechanical Analysis (DMA) are the most well known. The Oberst method [15–17] is used to measure the viscoelastic properties of relatively soft and highly damping materials. This method, described in Ref. [18], consists in resonance trials on beams damped by a

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viscoelastic material layer (free or stressed). Once the modal parameters (resonant frequency and loss factor) are determined, the storage modulus and the viscoelastic loss factor are calculated using analytical relationships [19,20]. Barbosa and Farage [21] used a finite element model formulation based on Golla–Hughes method (GHM) to describe the viscoelastic material. The parameters in the GHM rheological model are determined thanks to experimental tests based on Ross-Kerwin-Ungar relationships. Barkanov et al. [22] worked on an inverse technique to characterize the nonlinear mechanical properties of viscoelastic core layers in sandwich panels. Based on vibration tests, this technique consists in a numerical model and an identification procedure that makes use of a response surface method in order to decrease the computational efforts. Elkhaldi et al. [23] presented a viscoelastic parameters identification method for the generalized Maxwell model. They used automatic differentiation with a gradient algorithm to minimize a least-square error between numerical and experimental values. Elejabarrieta [24,25] identified the parameters of a fractional derivative model for viscoelastic sandwich beams by minimizing an error between predicted frequency response curves (FRF) and measured ones at specified control frequencies. Wassereau et al. [26] identified experimentally flexural and shear complex moduli of sandwich beams using the force analysis technique along with Timoshenko beam's theory and homogenization. Sun et al. [27] proposed an identification method based on response surface methodology, simplified FRF representation and an optimization approach to identify the frequency dependent mechanical parameter of unconstrained viscoelastic plates. In the aforementioned works, usually the viscoelastic layers are characterized independently; which means that the mechanical properties are determined layer by layer. These characterization methods do not take into account the interfaces between the layers or the possible imperfections of these interfaces.

In this paper, we propose a new inverse identification method based on a Rayleigh quotient for viscoelastic core layer material properties in sandwich structures. In our study, the viscoelastic layer's properties (shear modulus and loss factor) are determined from a numerical model of the three layered sandwich beam based on vibration tests performed on the whole structure. Our identification method is a non-destructive method that takes into account the structure in its globality.

In section 2, the experimental setup is described. In section 3, the new inverse identification method is detailed and validated by comparison to a standard optimization approach. In section 4, experimental vibration tests for different beam lengths are performed and the shear modulus and loss factor are determined by our method and fitted versus frequency.

2. Experimental measurements

2.1. Viscoelastic sandwich beams

The viscoelastic sandwich is composed of three layers: two elastic face layers and one viscoelastic core layer (Fig. 1). The three layers are glued to become an assembly. The viscoelastic material is studied in situ, i.e. when it is sandwiched between two elastic faces.

In this paper two types of sandwich beams (beam 1 and beam 2), distinguished by their respective core thicknesses, are considered. Geometrical and material properties are reported in Table 1.

2.2. Experimental setup

The experimental setup to measure sandwich beam frequency response curves is shown in Fig. 2. It is composed of a shaker, a laser vibrometer and a sandwich beam sample.

The shaker generates vibrations that are controlled and measured by a controller device (UCON system). The range of frequency excitation is between 4 and 1500 Hz. The vibration amplitude of the shaker is controlled thanks to an accelerometer (PCB Piezotronics - 352C33). The amplitude of the shaker is chosen to minimize nonlinear vibrations typically 0,02 mm displacement between 5 and 157, 5 Hz and a 1g acceleration between 157,5 and 1500 Hz. The amplitude of the beam's vibration is measured by a laser vibrometer, pointed on the free extremity of the beam.

The boundary condition of the beam is clamped-free. The beams are attached to the shaker thanks to an apparatus, which adjusts the length of the clamping. Four lengths are tested (318, 354, 400 and 475 mm).

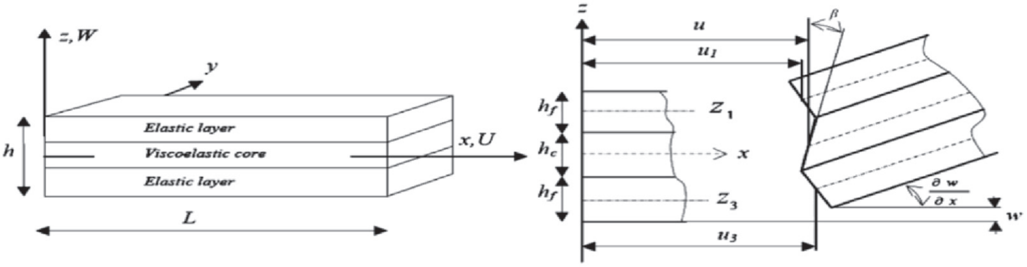

Fig. 1. Sandwich beam's geometry.