MODAL IDENTIFICATION OF THE ELASTIC PROPERTIES IN COMPOSITE SANDWICH STRUCTURES

Marco Matter, Thomas Gmür, Joël Cugnoni and Alain Schorderet
School of Engineering (STI)
Ecole polytechnique fédérale de Lausanne (EPFL)
Switzerland

ABSTRACT

Sandwich structures with composite face sheets and lightweight core are nowadays intensively used in engineering fields where high stiffness and strength combined with a reduced weight is of prime importance. Typical applications where this construction type is attractive include among others ship hulls, aircraft wings, racing car frames or sporting goods. Despite their attractiveness, sandwich constructions can only be used with confidence in engineering applications if their elastic properties are thoroughly characterized. The high orthotropy and heterogeneity of these materials, as well as their specific production process, increase however the difficulty to identify their constitutive parameters in comparison to multilayered composites or usual materials such as metals, so that a powerful and effective parameter identification method is highly desirable.

Modal identification procedures have shown great advantages over static characterization methods. Instead of performing a specific static test per elastic parameter on several specimens of the material to be identified, a dynamic identification requires only one full-field measure on a sole specimen, which reduces significantly the parameter characterization time. In addition, dynamic identification is a non-destructive technique which allows a measurement without altering the physical properties of the structural components under investigation. In this paper, the development of a modal method for identifying the elastic properties of composite sandwich structures is presented. Based upon a mixed numerical-experimental dynamic identification already validated on multilayered composite plates, the proposed method is extended to sandwich constructions and exhibits excellent characterization properties.

Dynamic identification techniques rely on the minimisation of the discrepancies between the natural frequencies and mode shapes of structures modelled with a highly accurate composite finite element formulation with adjustable elastic properties and the corresponding experimental quantities. By choosing appropriate error functionals which take into account not only the discrepancies between the predicted and measured natural frequencies but also the differences in amplitude, position or orthogonality between the simulated and measured mode shapes, the convergence of the estimated elastic parameters to the true values can be improved.

On the computational level, different finite element models have been investigated in order to define the most suitable numerical formulation for modelling sandwich structures. Since the sandwich plates considered were made of face sheets in a rigid orthotropic material such as carbon/epoxy embedding a softer core with a low density like foam or honeycomb, the difficulty in modelling such type of material lies in the proper representation of the discontinuity of the through-the-thickness displacement derivative at the interfaces of the sandwich components. As the displacement in the thickness direction shows a well pronounced zigzag variation due to the strong difference of the elastic properties between the face sheets and the core of sandwich constructions, the true displacement field can not be well estimated when using a multilayered shell finite element formulation based upon the first- or higher-order shear deformation theory. A *p*-order shell finite element model including also piecewise linear functions for the through-the-thickness displacement has been formulated. This model has been compared to several other numerical models such as the 3D solid orthotropic formulation in order to find the most powerful model in terms of accuracy and computation time in the identification process.

On the experimental level, a measurement setup, formed by a scanning laser vibrometer Polytec PSV200, a controlled pseudo-random and periodic chirp signal generator and an electro-dynamic shaker to generate the excitation of the specimens, has been mounted in an anechoic chamber (fig. 1). The correlation between the experimental tests and the numerical simulations is improved by choosing free boundary conditions for the structures tested, which ensures a good repeatability of the measures. Three sandwich composite plates have been selected, all of them being made of 0°/90° carbon/epoxy face sheets and a honeycomb (Nomex) core or two foam core of different thicknesses. They have been subjected to an excitation in the frequency range from 200 Hz to 15 kHz in order to find the lowest 15 natural frequencies and the corresponding mode shapes. Measured with a dynamic load cell, the input load ranged from 0 to 45 N. Captured with the laser interferometer, the response of the specimens to the excitation has been treated with a multi-degree-of-freedom curve fitting software to extract the modal data of interest (fig. 2).

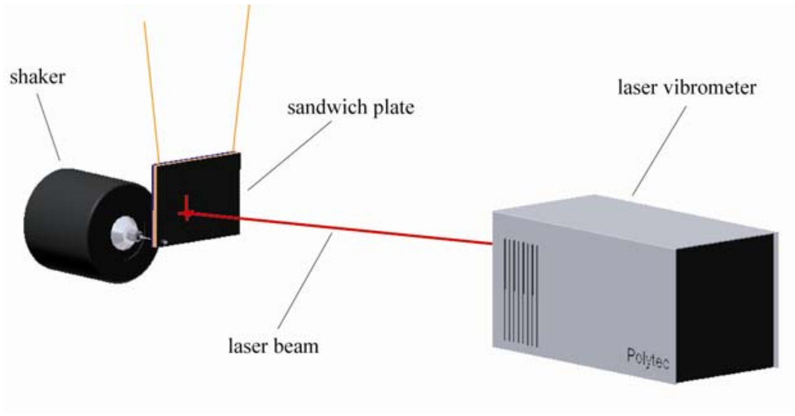

Figure 1 – Experimental setup.

On the optimisation level, adequate modal identification criteria have been defined for quantifying the residuals on the constitutive parameters during the identification iterations. Sensitive to all the material properties to be identified, original error norms which take into account all the modal data available have been developed. Based upon the natural frequencies, the mode shape components, the location of the nodal lines, and the diagonal and off-diagonal mode shape correlation coefficients associated to the classical modal assurance criterion (MAC), these error norms are weighted and combined in a global objective function which is minimized by using a classical Levenberg-Marquardt nonlinear least square optimisation algorithm. Required as in any minimization process, the derivatives of the objective function with respect to the elastic parameters to be identified are computed numerically with a finite difference scheme.

In a first step, different numerical models are compared and discussed using a theoretical test case of a sandwich plate with given elastic properties. From these investigations, it is concluded that, among the equivalent single layer models, only the finite element formulation based upon the *p*-order shear deformation theory and including a zigzag form for the through-the-thickness displacement approximation is sufficiently accurate for modelling sandwich structures. In a second time, several real identification examples with sandwich plates made of 0°/90° carbon/epoxy face sheets and a honeycomb or foam core are presented. It is also shown that the uniqueness of the parameter estimation is not necessarily guaranteed in sandwich constructions as two different sets of elastic properties can yield to the same dynamic behaviour. Overall, the proposed identification method can accurately determine the in-plane Young's moduli of the face sheets and the transverse and in-plane shear moduli of the core.

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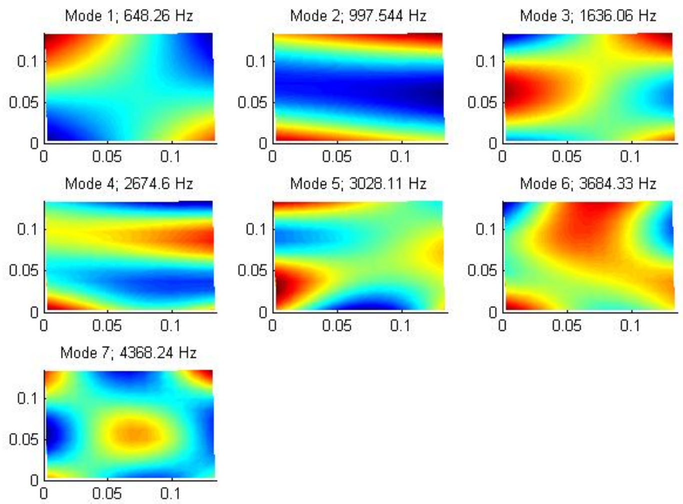

Figure 2 – First mode shapes of the sandwich plate.