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A parametric study on the stress analysis and transient response of thick-laminated-faced cylindrical sandwich panels with transversely flexible core

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ABSTRACT

In the present work the effects of important parameters such as core thickness, radius of curvature and sector angle on the static and dynamic response of composite cylindrical sandwich panels have been investigated using a higher-order sandwich panel theory (HSAPT). The presented higher-order theory, which applies first-order shear deformation shell theory (FSDT) for the face sheets and the equivalent elasticity theory for the core, is a rigorous approach that includes the higher-order effects incurred by the nonlinearity of the in-plane and transverse displacements of core. Equations of motion along with associated boundary conditions are derived by using Hamilton's principle. For simply-supported panels closed-form solutions can be achieved by Navier techniques. However, for dynamic analysis, the solution is obtained in the time domain by implementing Newmark method. Finally numerical parametric studies are performed to provide some insight into the roles of key variables that influence the static and dynamic response of sandwich panels.

1. Introduction

The need for highly efficient lightweight load-carrying panels and structures for many engineering fields such as aerospace and naval industries ensures that sandwich composite structures will continue to be in demand. A typical sandwich structure is composed of two laminated composite faces and a thick core made of foam or low-strength honey comb. This type of core is transversely flexible compared to face sheets which may significantly affect the overall behavior of the structure. To accommodate this feature, however; three-dimensional elasticity solution is accompanied by vast complications and computational efforts. As a result, two-dimensional models have been preferred and developed by deploying a set of approximations. On the other hand, due to incapability of earlier two-dimensional models categorized as equivalent single layer models (ESL) to accurately predict the overall behavior of sandwich structure with a transversely compliant core [1], attempts have been made to establish a more rigorous base for the numerical analysis regarding these structures.

In 1992 a new model for sandwich panels with transversely compliant core was proposed by Frostig and his coworkers [2]. The new higher order approach named high order sandwich panel theory (HSAPT) was applicable to any type of sandwich constructions and to any type of boundary conditions including cases in which the conditions at the upper skin differ from those at the lower one at the same section. Using this theory Frostig and Baruch [3] studied the free vibration of sandwich beams. In their analysis they used the same assumptions as those encountered in linear, elastic small deformation theory. They also considered the core as a two-dimensional elastic medium with negligible in-plane rigidity that transfers its inertial loads to the skins rather than resisting them by itself. Yang and Qiao [4] used high order sandwich panel theory to simulate the response of a soft-core sandwich beam subjected to a foreign object impact. They enhanced Frostig's model by considering the inertia forces of the core into the governing equations of motion in the core. Although in their model the core carries its inertial loads, the two computational models yield nearly identical result. In another study Frostig and Thomsen [5] investigated free vibration of sandwich panels with a flexible core based on the high-order sandwich panel theory. Two computational models were used and compared in order to determine the effects of the first model's discrepancy between the velocities of the core and its displacements. In the first model, velocity field in the core is assumed to vary linearly with height, which introduces inconsistency in the formulation. The second model assumes a polynomial description of the displacement fields in the core that is based

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on the displacement fields of the first model. In this case the unknowns are the coefficients of these polynomials in addition to the displacements of the face sheets. Also, in some other developed formulations [6–8] the inconsistency of the first model has been overcome by taking into account a nonlinear acceleration field in the core.

Some other relevant studies that employed HSAPT theory are reviewed below. Schwarts-Givli et al. [9] used the higher-order approach for the free-vibration analysis of fully bonded and delaminated unidirectional sandwich panels with a transversely flexible core. Malekzadeh et al. [10] developed an improved fully dynamic higher-order theory to analyze the low-velocity impact dynamic of a system which consists of a composite sandwich panel with transversely flexible core and multiple small impactors with small masses. They used First shear deformation theory (FSDT) for the face-sheets and three-dimensional elasticity for the soft core. The fully dynamic effects of the core layer (i.e., the mass inertia and the horizontal vibration of the core) were considered in their study. Afshin et al. [11] studied the static response of cylindrical sandwich panels with flexible core based on the high-order theory. In their work, a closed-form solution is developed for simply supported boundary conditions and the influence of parameters including the core to face sheets stiffness ratio and the core to face sheets thickness ratio was investigated. Free vibration analysis of sandwich panels with a core that is flexible and compliant in the vertical direction and with temperature-dependent mechanical properties is investigated by Frostig and Thomsen [12]. In another study they [13] also presented a non-linear analysis of a delaminated curved sandwich panel that was subjected to a thermal field or a mechanical loading or combined. Rahmani et al. [14] analyzed the free vibration of composite sandwich cylindrical shell with a flexible core using a higher order sandwich panel theory. They formulated the problem by using classical shell theory for the face sheets and an elasticity theory for the core.

It is also worth to mention that recently a new higher order shear and normal deformation theory has been developed [15–20] which provides an efficient method for the analysis of functionally graded sandwich plates and beams. In this new model, the zero traction boundary conditions on the free surfaces are satisfied without using shear correction factors and by partitioning the transverse displacement into the bending, shear and thickness stretching components, a reduced number of unknowns are obtained in comparison with other equivalent single layer shear deformation theories.

Frostig's higher order sandwich panel theory uses classical thin shell theory for the face sheets and a three-dimensional elasticity theory or equivalent one for the core. The application of the classical shell theory for the face sheets are expected to yield sufficiently accurate results when (i) the lateral dimension-to-thickness ratio of the face sheet is large; (ii) the dynamic excitations are within the low-frequency range; (iii) the material anisotropy is not severe. However, the application of this theory to layered anisotropic composite face sheets could lead to considerable errors in deflections, stresses and frequencies calculations. This issue motivates the development of the present model. The main advantage of the model used in this work is that it accounts for the transverse compressibility of the core and satisfies all equilibrium conditions with respect to the transverse shear stress in an exact sense.

This study follows the approach of Frostig and his coworkers to present a rigorous description of the static and dynamic behavior of curved sandwich panels. The derivation of the governing equations is presented based on the higher order model assuming that the panel is long enough to be in plane strain condition. First-order shear deformation shell theory is employed to enhance Frostig's model and continuity requirements of interlaminar shear stresses as well as boundary traction conditions are imposed by introducing shear correction factor that modifies the effect of none uniform shear strain distribution and is calculated by using an iterative formulation based on the "shear strain energy equivalence". Finally numerical results are presented and for some special cases the results obtained by the present analysis are compared with the classical solutions for the face sheets to assess the accuracy of the latter in predicting the response of the sandwich panels. Moreover, a parametric study is conducted to investigate the effect of varying parameters such as thickness ratio, width to thickness ratio and sector angle on the static and dynamic response of circular cylindrical composite sandwich panels with a transversely flexible core. Therefore, it is suggested that the present study can be applied as a useful guideline for the design of advanced cylindrical sandwich panels.

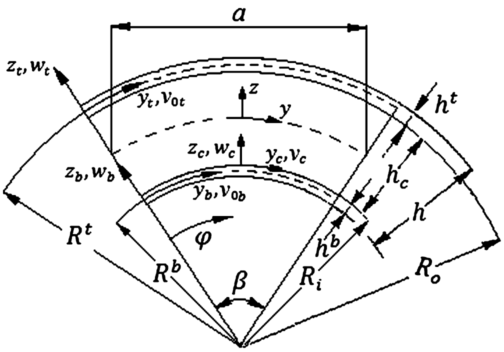

Fig. 1. Geometry, deformations and sign conventions.

2. Analytical model

Consider a long cylindrically curved sandwich panel with a section shown in Fig. 1. In the following, indexes t, b refer to the top and bottom faces of the panel, respectively. The panel is composed of two composite laminated faces and a transversely compliant core. The mathematical model presented here establishes the higher order model of curved panels developed by few researchers earlier [14,21–24]. According to this higher order concept, the core has shear resistance, but is free of in-plane normal and shear stresses. This assumption is practically correct for foam cores, since its flexural rigidity is at least of two to three orders smaller than those of the face sheets. It should be noted that as the core of the sandwich panel becomes stiffer in comparison with the face sheets, this approximation begins to break down because the in-plane stresses in the core are no longer ignorable in comparison with the transverse stresses. The face sheets of the panel are assumed to be moderately thick. Kinematic relations of the components are those of small deformations and no priori assumptions on the deformation fields through the thickness of the core are made. Governing equations of motion and the boundary conditions are derived following the steps of the HSAPT approach and using the Hamilton variational principle:

$$\delta \int_{t_1}^{t_2} (T - U - V)dt = 0 \tag{1}$$

where T is the kinetic energy, U is the internal potential strain energy and V is the potential energy of the external loads. The variation of the internal potential energy in terms of cylindrical coordinates for the long sandwich panel can be expressed as: