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Three-Dimensional Analyses of Functionally Graded Multi-Layered Systems

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Abstract

Functionally Graded Materials (FGMs) are composites with continuously varying volume fractions of their constituent homogeneous phases. When the characteristic length scale of such variations is much larger than the size of the phases, the model of the inhomogeneous solids is able to describe the macroscopic behaviour of these materials by means of homogenization techniques. By considering materials in which this assumption is possible, some elastic solutions for graded inhomogeneous materials have been obtained in the literature in order to tailor the material parameters for specific requirements. The main purpose of the paper is devoted to analyse the effects of FGM elements in sandwich structures, where the mismatch between the properties of the core and the face-sheets can produce interface damage especially when the structures are subjected to extreme conditions. Two different cases concerning the bending of a thick circular sandwich plate are investigated in the framework of the linear elasticity theory: (a) sandwich plates with homogeneous face sheets and FGM-core and (b) sandwich plates with FGM face sheets and homogeneous core. The related elastic solutions are obtained in the framework of the elasticity theory and explicit solutions are discussed by considering only the first contribution of the series in order; in such a way, we have a solution in closed-form and no convergence effects on the solutions. Three different aspects are studied in detail in terms of the geometric and material parameter: the semi-inverse solution method adopted with the consequence on boundary conditions, the non-linear behaviour of the radial displacement and, the shear and circumferential stress behaviour in the thickness of the plate. A comparative study between sandwich with FGM elements and conventional multi-layered systems is performed in order to highlight the effects of the inhomogeneity.

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1. Introduction

In multi-layered systems the mismatch between the properties of the single layers can produce interface damages; in order to reduce these effects, one of the recent alternatives, adopts ~~of~~ functionally graded materials (FGMs) for the entire multi-layered structure or for single elements [1,2,3]. In this paper, the interest is devoted to sandwich plates to reduce interface delamination effects by using FGM core or face-sheets. Different approaches are presented in the literature to describe FGM structures and much of the work has been carried out by using refined plate theories or/and numerical methods [4,5,6].

In the framework of elasticity theory, some analytical solutions have recently been obtained by Kashtalyan and Meshykova [7,8] for squared sandwich panels with graded elements (core or face-sheets). This paper presents some analytical solutions for circular sandwich plates with FGM elements subjected to axisymmetric loading conditions. The Young modulus in the graded elements is assumed exponentially dependent on the transverse direction while the Poisson ratio is uniform. The circular geometry requires ~~to~~ solving inherent mathematical difficulties concerning the solution method and the boundary conditions. A particular representation form, that reduces the field equations in terms of potential functions for any heterogeneous or homogeneous layer, is adopted [9]. Then, a semi-inverse solution method is used to solve the partial differential equation systems in terms of Bessel's functions and, as consequence of the solution method, particular boundary conditions on the lateral surface of the plate are required.

Numerical investigations allow us to highlight the effects of graded elements in sandwich plates in comparison with conventional homogeneous sandwich structures. Further, the solutions may give rise a benchmark to investigate the agreement with numerical or structural refined theory results.

2. Problem Statement

The geometry of the sandwich plates is described in Fig.1. We chose a cylindrical coordinate system with the middle plane of the sandwich of radius b and total thickness h; the face-sheet and core thicknesses are denoted with h_f and $2h_c$, respectively.

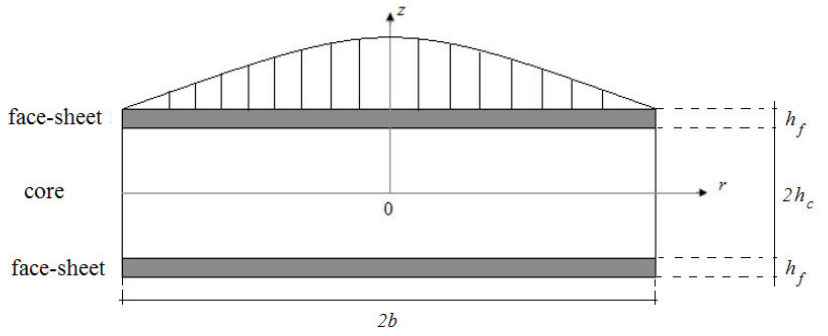

Fig. 1. Circular sandwich plate geometry and loading conditions

This study investigates the bending of the sandwich plate by considering transversal axisymmetric loading conditions and partial boundary conditions on the lateral surface; this, o better control the consequence of the semi-inverse solution method adopted. In particular, we consider free traction on the bottom of the sandwich and transversal load on the upper surface in the form: