Thin-Walled Structures 90 (2015) 150–158

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

A refined FSDT for the static analysis of functionally graded sandwich plates

J.L. Mantari [a,*], E.V. Granados [b]

[a] Faculty of Mechanical Engineering, Universidad de Ingeniería y Tecnología, Av. Cascanueces 2221, Santa Anita, Lima, Peru
[b] Faculty of Mechanical Engineering, National University of Engineering, Av. Túpac Amaru 210, Rimac, Lima, Peru

ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form
9 January 2015
Accepted 15 January 2015
Available online 10 February 2015

Keywords:
Shear deformation theory
FSDT
Static analysis
Functionally graded materials

ABSTRACT

This paper presents a static analysis of functionally graded plates (FGPs) by using a new first shear deformation theory (FSDT). This theory contains only four unknowns, with is even less than the classical FSDT. In this paper a simply supported *FG* square sandwich plate is subjected to a bi-sinusoidal load. The governing equations for static bending analysis are derived by employing the principle of virtual works. These equations are then solved via Navier-type, closed form solutions. The accuracy of the present theory is ascertained by comparing it with various available solutions in the literature.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Functionally graded materials (FGMs) can be defined as advanced materials having graded transition in mechanical properties, either continuous or in fine, discrete steps, across the interface. This material is produced by mixing two or more materials in a certain volume ratio (commonly ceramic and metal). FGMs have been proposed, developed and successfully used in industrial applications since 1980s [1]. These materials were initially designed as a thermal barrier for aerospace structures and fusion reactors. They are now being developed for general use as structural components subjected to high temperatures. The areas where FGM offer potential improvements and advantages in engineering applications include a reduction of in-plane and transverse through-the-thickness stresses, prevention or reduction of the delamination tendencies in laminated or sandwich structures, improved residual stress distribution, enhanced thermal properties, higher fracture toughness, and reduced stress intensity factors [2].

Several analytical and numerical formulations to model the behavior of single and multilayered structures are available in the literature. Among them, the classical first-order shear deformation theory (FSDT) based on Raissner and Mindlin, assume constant transverse shear stresses in the thickness direction, thus the theory need a shear correction factors to adjust for unrealistic variation of the shear strain/stress. Nguyen et al. [15] studied the shear correction factor for FGMs. The authors showed that the shear correction factor for FGMs are not the same as for homogeneous plates, in fact, they showed that the shear correction factor is as a function of the ratio between elastic moduli of constituents and of the distribution of materials through the models. In this paper, for simplicity purposes, the considered shear correction factors are as in the paper by Carrera et al. [5].

Researchers have investigated the behavior of functionally graded plates (FGPs) under mechanical loads using, mostly, both the classical FSDT and the higher-order shear deformation theories (HSDT). In this paper, relevant works on FGM based on the classical and modified FSDTs was reviewed and presented in what follows. Zenkour [3] studied the bending analysis of FGPs resting on elastic foundation using the refined sinusoidal shear deformation theory, FSDT results were also presented. Singha et al. [4] investigated the nonlinear behavior of FGPs using the finite element method based on the FSDT. The authors evaluated the shear correction factors employing the energy equivalence principle.

Carrera et al. [5] evaluated the effect of thickness stretching in functionally graded (*FG*) plates and shells by using Carrera's Unified Formulation (CUF), FSDT results were also presented. Valizadeh et al. [6] studied the FGPs using a non-uniform rational B-spline based on FEM. The plate kinematics is based on the FSDT. Thai and Choi [7] presented a simple FSDT with four unknowns for *FG* plate considering a division of the transverse displacement w into bending and shear parts. (i.e. $w = w_b + w_s$). Thai et al. [8] analyzed the *FG* sandwich plates composed of *FG* face sheets and an isotropic homogeneous core by using a FSDT with four unknowns.

In the present paper, the static analysis of FGPs is studied by using a new FSDT with four unknowns in which instead of

* Corresponding author. Tel.: +511 3540070; Mobile: +51 96224551.
E-mail address: jmantari@utec.edu.pe (J.L. Mantari).

http://dx.doi.org/10.1016/j.tws.2015.01.015
0263-8231/© 2015 Elsevier Ltd. All rights reserved.

derivative terms in the displacement field, integral terms are presented for the first time. Such displacement field, which can be further implemented in higher order shear deformation theories, may require new mathematical strategies to numerically solve the present theory due to its novelty. The simply supported *FG* plate and sandwich plate is subjected to a bi-sinusoidal load. The mechanical properties of the plates are assumed to vary in the thickness direction according to a power law distribution in terms of the volume fractions of the constituents. The governing equations of the FGPs are derived by employing the principle virtual works. These equations are then solved via Navier solution. The accuracy of the present code is verified by comparing it with other HSDTs. Although similar results as the classical FSDT are found, the reduced number unknowns of this theory play a key importance in the performance. Consequently, the numerical solution may be of paramount interest in future works.

2. Theoretical formulation

The mathematical model was built to solve both: (A) functionally graded plates and (B) sandwich plates. The plates of uniform thickness "h", length "a", and width "b" are shown in Fig. 1. The rectangular Cartesian coordinate system x, y, z, has the plane $z=0$, coinciding with the mid-surface of the plates.

2.1. Functionally graded plates

The material properties for the plate of type A (Fig. 1a) vary through the thickness with a power law distribution, which is given below (Fig. 2a):

$$P_{(z)} = (P_t - P_b)V_{(z)} + P_b \tag{1a}$$

$$V_{(z)} = \left(\frac{z}{h} + \frac{1}{2}\right)^p, \tag{1b}$$

$$-\frac{h}{2} \le z \le \frac{h}{2}. \tag{1c}$$

where P denotes the effective material property, P_t and P_b denote the property of the top (fully ceramic) and bottom (fully metal)

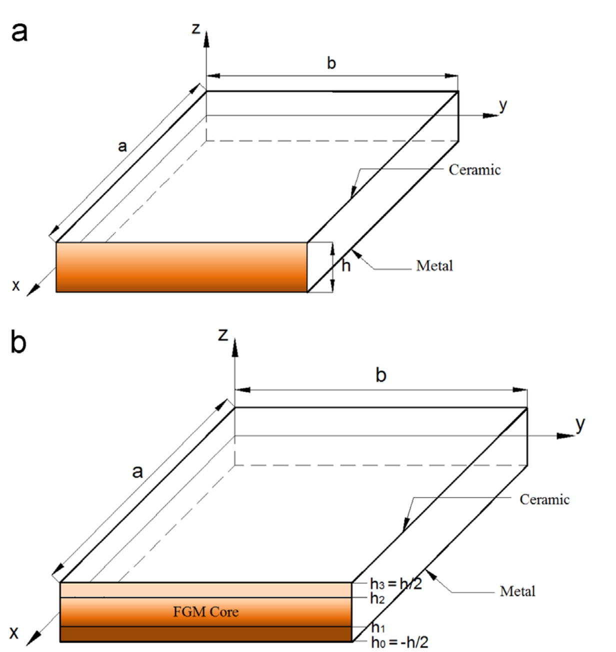

Fig. 1. Geometry of functionally graded plates. (a) *FG* plate. (b) Sandwich plate with an *FG* core and isotropic skins.

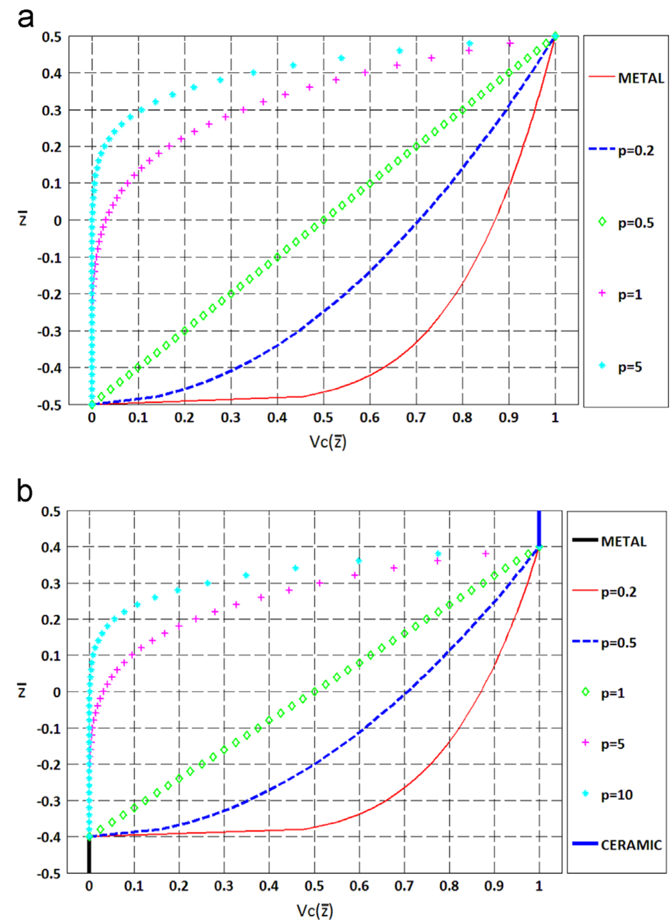

Fig. 2. Functionally graded function V_C along the thickness of an *FG* plate for different values of the index "p". (a) *FG* plate. (b) Sandwich plate with an *FG* core and isotropic skins.

faces of the plate, respectively, and "p" is the exponent that specifies the material variation profile through the thickness. The effective material properties of the plate, including Young's modulus, E, and shear modulus, G, vary according to Eqs. (1a) and (1b), and Poisson ratio, "ν" is assumed to be constant.

In the plate of type B, the bottom skin is isotropic (fully metal) and the top skin is isotropic (fully ceramic). The core layer is graded from metal to ceramic so that there are no interfaces between core and skins (see Fig. 1b).

The volume fraction in the core is obtained by adapting the power law distribution (Eq. (1b)):

$$V_{(z)} = \left(\frac{z - h_1}{h_{core}}\right)^p, \tag{2a}$$

$$h_1 \le z \le h_2 \tag{2b}$$

where h_{core} is the thickness of the core.

2.2. Displacement base field

The displacement field of the new theory is given as follows:

$$\overline{u}(x,y,z) = u(x,y) - zk_1 \int \theta(x,y)dx, \tag{3a}$$

$$\overline{v}(x,y,z) = v(x,y) - zk_2 \int \theta(x,y)dy, \tag{3b}$$

$$\overline{w}(x,y,z) = w(x,y). \tag{3c}$$

Download English Version:

https://daneshyari.com/en/article/308784

Download Persian Version:

https://daneshyari.com/article/308784

Daneshyari.com