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Vibration and buckling analysis of functionally graded sandwich beams by a new higher-order shear deformation theory

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A B S T R A C T

This paper proposes a new higher-order shear deformation theory for buckling and free vibration analysis of isotropic and functionally graded (FG) sandwich beams. The present theory accounts a new hyperbolic distribution of transverse shear stress and satisfies the traction free boundary conditions. Equations of motion are derived from Lagrange's equations. Analytical solutions are presented for the isotropic and FG sandwich beams with various boundary conditions. Numerical results for natural frequencies and critical buckling loads obtained using the present theory are compared with those obtained using the higher and first-order shear deformation beam theories. Effects of the boundary conditions, power-law index, span-to-depth ratio and skin-core-skin thickness ratios on the critical buckling loads and natural frequencies of the FG beams are discussed.

1. Introduction

Functionally graded materials (FGMs) are composite materials formed of two or more constituent phases with a continuously variable composition. Sandwich structures are widely employed in aerospace and many other industries. These structures become even more attractive due to the introduction of FGMs for the faces and the core. Typically, there are three typical FG beams: isotropic FG beams, sandwich beams with homogeneous core and FG faces, and sandwich beams with FG core and homogeneous faces.

It is known that the behaviours of isotropic and FG sandwich beams can be predicted by classical beam theory (CBT) [1–5], first-order shear deformation beam theory (FSBT) [6–12] and higher-order shear deformation beam theory (HSBT) [1,13–31] or three-dimensional (3D) elasticity theory [32–34]. It should be noted that Carrera et al. [23,24] developed Carrera Unified Formulation (CUF) which can generate any refined theories for beams, plates and shells. This formulation was used extensively for various structural problems and only a few of them are cited here, for instance, static and vibration analysis of FG beams [25–27] and FG plates and shells [28–31]. It is well-known that the CBT is applicable to slender beams only. For moderate beams, it underestimates deflection and overestimates buckling load and natural frequencies due to ignoring the shear deformation effect. In order to include this effect, a shear correction factor is required for FSBT but not for HSBT. However, the efficiency of the HSBT depends on the appropriate choice of displacement field which is an interesting subject attracted many researchers [1,14,15,19,22,35–40].

The objective of this paper is to present a new higher-order shear deformation theory for buckling and vibration analysis of isotropic and FG sandwich beams. Equations of motion are derived from Lagrange's equations. The FG beam is assumed to have isotropic, two-constituent material distribution through the depth, and Young's modulus is assumed to vary according to power-law form. Analytical solutions are derived for various boundary conditions to investigate the effects of the boundary conditions, power-law index, span-to-depth ratio and skin-core-skin thickness ratios on the critical buckling loads and natural frequencies of the FG beams.

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2. Theoretical formulation

2.1. FG sandwich beams

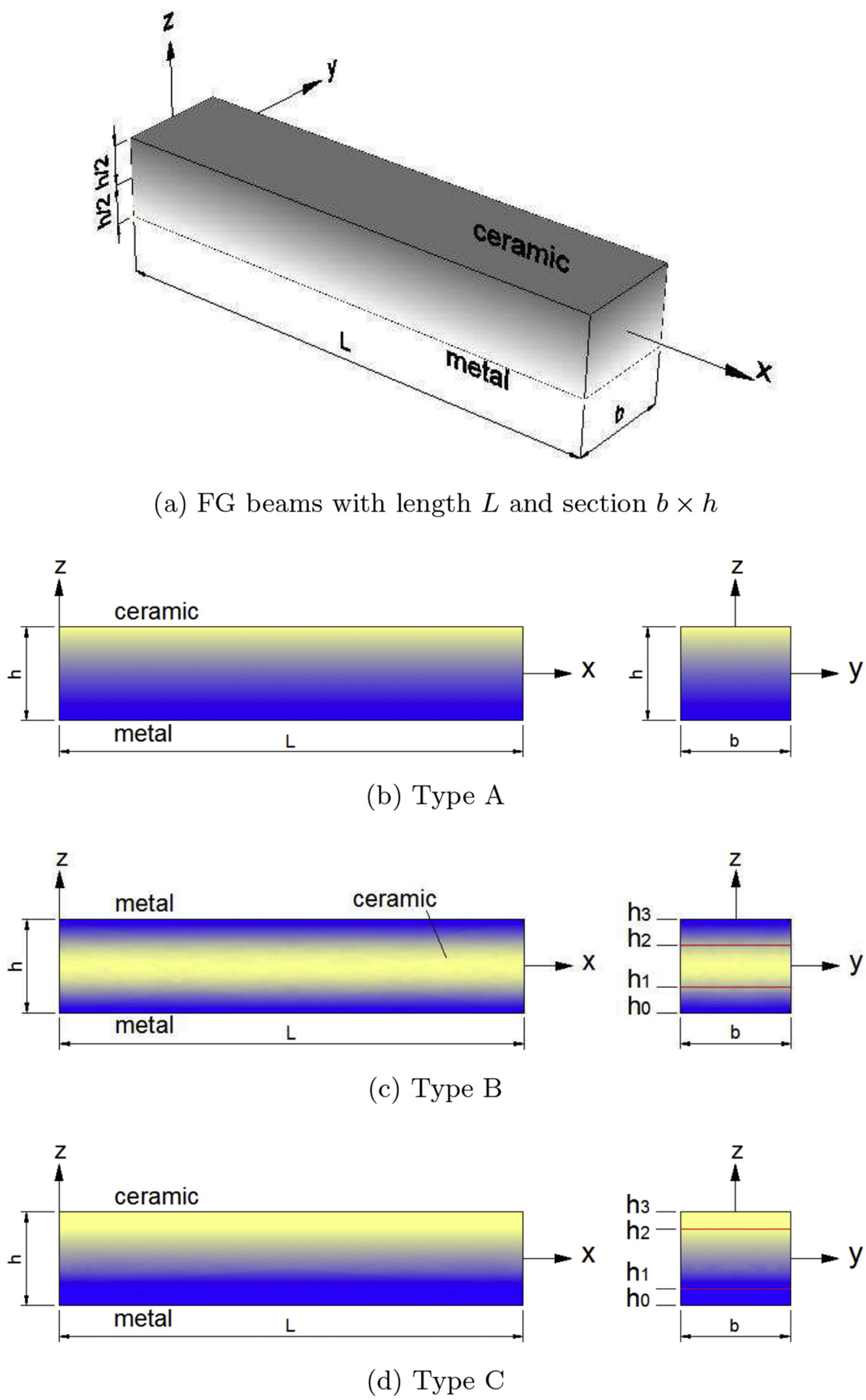
Consider a beam as shown in Fig. 1 with length L and uniform section $b \times h$. The beam is made of a mixture of ceramic and metal isotropic materials whose properties vary smoothly through the depth according to the volume fractions of the constituents. Three different types of the FG beams are considered: isotropic FG beams (type A), sandwich beams with FG faces and homogeneous core (type B), and sandwich beams with FG core and homogeneous faces (type C).

2.1.1. Type A: isotropic FG beams

The beam of type A is graded from metal located at the bottom surface to ceramic material at the top surface (Fig. 1b). The volume fraction of ceramic material V_c is given as follows:

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

where p is the scalar parameter, which is positive and $z \in [-h/2, h/2]$.



(a) FG beams with length L and section $b \times h$

(b) Type A

(c) Type B

(d) Type C

Fig. 1. Geometry of isotropic and FG sandwich beams.