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Free vibration and mechanical buckling of plates with in-plane material inhomogeneity - a three dimensional consistent approach

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Abstract

In this article, we study the free vibration and the mechanical buckling of plates using a three dimensional consistent approach based on the scaled boundary finite element method. The in-plane dimensions of the plate are modeled by two-dimensional higher order spectral element. The solution through the thickness is expressed analytically with Padé expansion. The stiffness matrix is derived directly from the three dimensional solutions and by employing the spectral element, a diagonal mass matrix is obtained. The formulation does not require ad hoc shear correction factors and no numerical locking arises. The material properties are assumed to be temperature independent and graded only in the in-plane direction by a simple power law. The effective material properties are estimated using the rule of mixtures. The influence of the material gradient index, the boundary conditions and the geometry of the plate on the fundamental frequencies and critical buckling load are numerically investigated.

Keywords: vibration, buckling, scaled boundary finite element method, functionally graded material, in-plane material inhomogeneity.

1. Introduction

The introduction of new class of engineered materials, coined as functionally graded materials (FGMs) has spurred the interest among researchers to study the response of structures with these materials. The FGMs are characterized by *smooth and continuous* transition of material properties from one surface to another. Typically FGMs are made from a mixture of a ceramic and metal. The ceramic constituent provides thermal stability due to its low thermal conductivity, whilst the metallic phase provides structural stability. FGMs eliminate the sharp interfaces existing in laminated composites with a gradient interface and are considered to be an alternative material in many engineering applications. The material properties can be graded in the thickness direction, in the in-plane or in both the directions. It can be seen from the literature that considerable attention has been devoted to functionally graded material plates with properties graded in the thickness direction [26, 8, 7, 27]. From the literature, it can be seen that the static and the dynamic response of functionally graded material plates and shells is studied extensively. It is beyond the scope of this paper to review the literature on plate/shells with material properties graded in the thickness direction. Interested readers are referred to the literature and references therein and a recent review by Jha and Kant [13]. To the author's knowledge there are only a few investigations on the structural response of structures in which the material is graded in the in-plane direction or in both directions [21, 24, 23, 9, 18, 17, 32]. Qian and Ching [24] and Qian and Batra [23] optimized the fundamental frequency of bi-directional[2] functionally graded beams and plates by employing meshless local Petrov Galerkin method. By employing element free Galerkin method, Goupee and Vel [9] optimized the natural frequency of bidirectional functionally graded beams. Nemat-Alla [21] by employing the rule of mixtures studied the thermal response of FGM structures graded in both the directions. Lü *et al.,* [18] derived semi-analytical solutions based on differential quadrature method for beams graded in both the directions. It was observed that the thermal stresses can be reduced by bi-directional functionally gradation instead of the conventional unidirectional functionally graded materials. Very recently, Liu *et al.,* [17] and Uymaz *et al.,* [32] studied the fundamental frequency of

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[2] material properties graded in the thickness and in the in-plane direction