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Static, free vibration, and buckling analysis of functionally graded plates using the strain-based finite element formulation

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Abstract In the current investigation, the novelty lies in the formulation of a novel four-node rectangular finite element with six degrees of freedom per node using the strain approach and first-order shear deformation theory, therefore, this is the first article to use this approach to analyze the static, free vibration, and buckling behaviors of functionally graded. The properties of FGM vary continuously through the thickness direction according to the volume fraction of constituents defined by a simple power law function. The notion of a neutral surface is presented to prevent membrane bending coupling. The displacement functions of the suggested element which possess higher-order expressions, is based on assumed functions of strain that satisfy both rigid body modes and compatibility equations. The performance of the developed element is verified and compared with the published results in the literature and excellent agreement is observed. The influence of the geometrical, material properties, and loading types with different boundary conditions on the bending, free vibration, and buckling analysis of FGM plate are also studied and discussed for the first time using the strain-based finite element formulation.

Keywords Static · Free vibration · Buckling · Reissner–Mindlin · Functionally graded · Strain approach

1 Introduction

Functionally graded materials (FGM) are new composite materials that were initially developed in 1984 by a team of researchers in Japan. They are commonly composed of a combination of ceramic and metal. The properties of FGM change continuously and smoothly from one face to the other and therefore avoid the interfacial stress concentration observed in laminated composites. These novel materials were first proposed as ways to produce a thermal barrier material because of their ductility given by the metal component and high temperature resistance from the ceramic component [1]. FGM is developed for application in different industries and engineering disciplines. Therefore, due to their excellent properties, several authors have been motivated to investigate their static, free vibrational and buckling responses by applying different analytical and numerical approaches based on different theories, including the first-order shear deformation theory (FSDT) and the higher-order shear deformation theory (HSDT). For the first one, Reddy [2] analyzed the bending analysis of functionally graded (FG) plates using third-order shear deformation plate theory (TSDT). Zenkour [3] proposed an analytical results for the bending behavior of composite plates exposed to thermo-mechanic loading based on the HSDT. Vel and Batra [4, 5] introduced a three-dimensional (3D) precise model for analyzing thermo-mechanical deformations and forced vibrations in FG rectangular plates. Matsunaga [6] analyzed the fundamental frequency and buckling stress of FG plates using the two-dimensional (2D) HSDT.

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