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REVIEW PAPER

Static, free vibration, and buckling analysis of functionally graded plates using strain approach and Reissner–Mindlin elements

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Abstract
The novelty of the present work lies in the development of a new four-node rectangular finite element using strain-based and Reissner–Mindlin theory. This paper is the first to apply this innovative approach to study the static, free vibration, and buckling responses of functionally graded materials (FGMs) plates. The mechanical properties of the FGM plate are considered to vary along the thickness direction by the power-law distributions. The notion of a neutral surface has been used to prevent the stretching–bending effect. The developed element has six degrees of freedom (DOFs) per node, obtained by combining two strain-based elements. The first one is a membrane which has three DOFs per node, and the second one is a Reissner–Mindlin plate which has three DOFs per node. The displacement fields of these components are represented by higher-order expressions based on the strain approach, which satisfy both rigid body modes and compatibility equations. The performance of the proposed element is evaluated through various numerical problems, and the results are compared with those published in the literature, showing good agreement. The impact of the gradient index, side-to-thickness ratio, aspect ratio, and loading types on the stresses, transverse displacements, frequency response, and critical buckling load of FGM plates is also investigated and discussed.

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

1 Introduction

In recent decades, the notion of functionally graded materials (FGM) has emerged from the work of a Japanese scientist in 1984 [1], which are used in industrial environments due to their excellent performance compared to conventional materials. FGM is a family of composite inhomogeneous materials consisting of a combination of isotropic materials, generally ceramics and metals, and it has many advantages, including progressive and continuous changes in their mechanical and thermal characteristics across the thickness, which prevents problems associated with traditional laminated composite structures, like higher inter-laminar stresses between the layers of a composite laminate [2].

As a result, these materials are attracting significant attention in various engineering disciplines, such as aerospace, mechanical, automotive, civil, and biomedical engineering. Many researches have been studied for static, free vibrational, and buckling behaviors of FGM beams, plates, and shells using several analytical and numerical approaches, relying on various theories, including classical plate theory (CPT), which neglects the effects of transverse shear deformation [3–7], first-order shear deformation theory (FSDT) having a linear variation in displacements [8–12], and higher-order shear deformation theory (HSDT) involving higher-order variations in displacements across the plate thickness, such as third-order shear deformation plate theory (TSDT), sinusoidal shear deformation plate theory (SSDT), and hyperbolic shear deformation plate theory (HDT) [13–23].

Several developers have employed the strain approach to design finite elements that are both efficient and durable. Initially, Ashwell et al. [24] introduced this methodology specifically for curved elements. Subsequently, this approach was employed in the analysis of shell structures [25–27]. It was later expanded to encompass plane-elasticity elements

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