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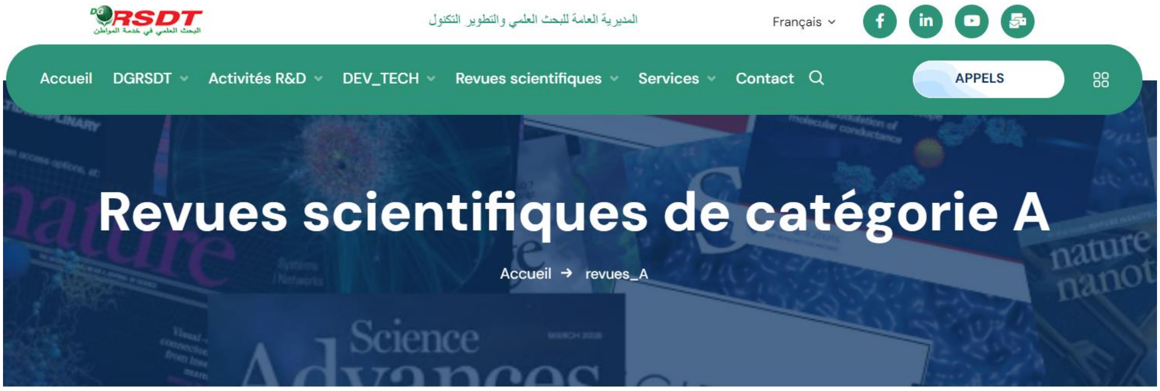

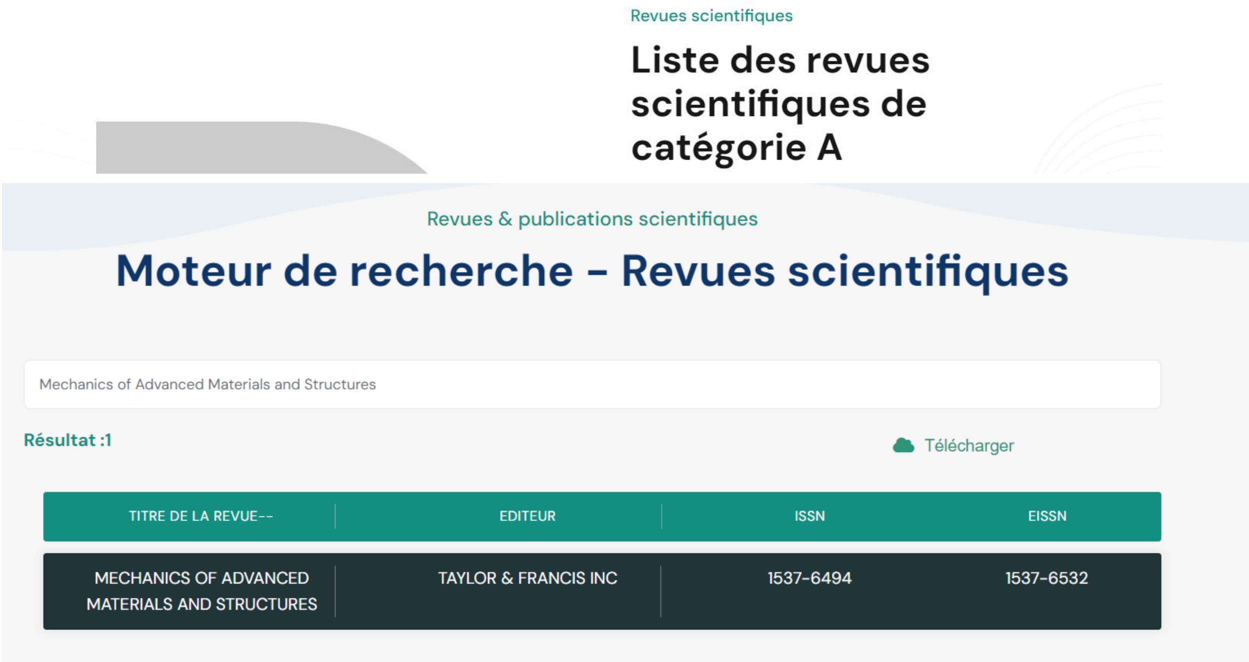

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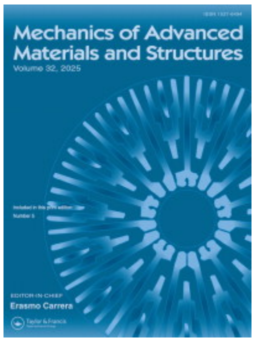

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A novel strain-based approach with high-order shear deformation for enhanced static and buckling performance of functionally graded plates

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ABSTRACT

This work presents the first study investigating the static and buckling behavior of functionally graded rectangular plates using a strain-based approach combined with high-order shear deformation theory and a newly developed sinusoidal function. The novelty of this study lies in the development of a novel sinusoidal function for high-order shear deformation theory, the application of the strain-based approach within this framework, and the combination of these methods for the analysis of functionally graded plates. The sinusoidal function, derived by comparing the energy of shear deformation based on three-dimensional elasticity theory and Reissner–Mindlin theory, plays a critical role in reducing the number of unknowns from six to five. This reduction is achieved by enforcing zero transverse shear stress at the top and bottom surfaces and assuming a sinusoidal distribution of transverse shear strains through the thickness. The material properties of the functionally graded plate vary through the thickness according to a power-law distribution. The resulting element, a superposition of membrane and bending elements, eliminates membrane-bending coupling through the neutral plane concept. Stiffness and geometric matrices are derived using the potential energy principle. A parametric study is conducted to investigate the effects of key parameters on the static and buckling behavior of the plates. Numerical results, validated against literature using various meshes, demonstrate the accuracy and reliability of the proposed method for both static and buckling analyses. This work provides a robust and efficient tool for analyzing functionally graded plates in engineering applications such as aerospace, automotive, and civil structures.

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KEYWORDS
Static; buckling behavior; functionally graded plate; strain-based approach; high-order shear deformation theory

1. Introduction

Functionally Graded Plates (FGPs) are composite structures characterized by a gradual variation in material properties across their thickness. This gradient can be engineered to achieve specific mechanical, thermal, or other functional characteristics, making FGPs suitable for various applications in engineering and materials science. FGPs are used in fields ranging from aerospace to biomedical engineering, offering enhanced performance and adaptability to diverse operational conditions [1]. The analysis of FGPs employs several advanced methodologies to understand their behavior under various conditions. The Finite Element Method (FEM) is a crucial analytical tool for studying FGPs, enabling detailed modeling of their complex behavior. It is particularly advantageous for FGPs due to its ability to handle complex geometries and varying material properties that characterize these plates. Advanced FEM models have significantly improved the accuracy of predicting bending, vibration, and stability behaviors, validating results against higher-order theories and experimental data [2–5].

The analysis of FGPs has significantly advanced with the development of shear deformation theories, notably the first-order shear deformation theory (FSDT) and higher-order shear deformation theories (HSDT). FSDT, introduced by Reissner and Mindlin [6], accounts for transverse shear deformation with a linear shear strain distribution across the thickness. This approach is efficient for thin and moderately thick plates, though it requires a shear correction factor to compensate for inaccuracies arising from its assumptions. This theory has been extensively adopted in the academic community as a robust analytical framework for investigating the mechanical behavior of FGPs. It has been widely applied in static bending and free vibration analyses, offering reasonable accuracy for various boundary conditions (BCs) and loading scenarios [7]. Additionally, FSDT has proven effective in examining the buckling behavior of FGPs, leveraging its ability to capture the influence of material gradation properties, making it a cornerstone in advanced plate mechanics [8–11]. In contrast, HSDTs provide a more detailed representation by incorporating nonlinear variations of in-plane and transverse displacements

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