

PROCEEDINGS

Stochastic Free Vibration Analysis of Porous Functionally Graded Plates in Thermal Environments Based on Direct Probability Integral Method

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ABSTRACT

The dynamic response of functionally graded material (FGM) structures in high-temperature environments is highly sensitive to the temperature-dependent nature of constituent properties and inherent manufacturing uncertainties. Geometric micro-porosities with even or uneven gradient distributions and the spatial variability of material constituents significantly alter the structural stiffness and thermal stress distributions. To quantify these effects, this study presents a non-intrusive stochastic finite element framework based on the direct probability integral method to evaluate the stochastic free vibration of porous FGM plates under nonlinear thermal fields. The spatial randomness of material properties is modeled via random fields and discretized using the Karhunen-Loève (K-L) expansion. To balance computational efficiency and stochastic dimensionality, a mean square error criterion is adopted to determine the optimal K-L truncation order, controlling the representation error strictly within 5% across the considered correlation lengths. To capture the thermo-mechanical coupling, the equivalent elastic modulus and thermal expansion coefficient are treated as functions of both temperature and thickness coordinates, with thermal strains explicitly integrated into the constitutive relations. Numerical validations demonstrate that the calculated deterministic frequencies and stochastic variation trends align well with existing benchmark solutions. Furthermore, the results quantify how the porosity distribution patterns and the correlation lengths of the random fields reshape the probability density functions of the natural frequencies under thermal loading. By efficiently propagating high-dimensional spatial uncertainties without relying on extensive Monte Carlo simulations, the proposed framework offers a computationally tractable approach for the reliability evaluation of FGM structures in complex thermo-mechanical environments.

KEYWORDS

Functionally graded materials; thermal environment; stochastic free vibration; random field; Karhunen-Loève expansion

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