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Bending and free vibration analyses of in-plane bi-directional functionally graded plates with variable thickness using isogeometric analysis

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Abstract

This article is firstly concerned with bending and free vibration analyses of in-plane bi-directional functionally graded (IBFG) plates with variable thickness in the framework of isogeometric analysis (IGA). The plate thickness is smoothly altered in both $x-$ and $y-$axes by a predetermined power law. Two types of power-law material models with the symmetrical and asymmetrical volume fraction distribution are suggested to characterize the in-plane material inhomogeneity. A non-uniform rational B-spline (NURBS) surface for simultaneously representing both variable thickness and volume fraction distribution of each constituent is employed. By using the $k-$refinement strategy, the C^0-continuous requirement at symmetrical material interfaces can be achieved, yet still ensuring material gradations elsewhere owing to the prominent advantage of NURBS basis functions in easily controlling continuity. Effective material properties are then evaluated by either the rule of mixture or the Mori-Tanaka scheme. An analysis NURBS surface separately created with the foregoing NURBS surface is utilized to exactly describe geometry and approximately solve unknown solutions in finite element analysis (FEA) based on the IGA associated with a generalized shear deformation theory (GSDT). The Galerkin C^1-continuous isogeometric finite element model is therefore simply achieved due to the possibility of flexibly meeting high-order derivatives and continuity of analysis NURBS functions. In addition, no shear correction factors exist in the present formulation, although shear deformation effects are still considered. The influences of variable thickness, material property, length-to-thickness ratio, boundary condition on bending and free vibration responses are investigated and discussed in detail through several numerical examples.

Keywords: In-plane bi-directional functionally graded (IBFG) plates; Variable thickness; Isogeometric analysis (IGA); NURBS; generalized shear deformation theory (GSDT).

1. Introduction

As known, in mid-1980s, Japanese scientists first discovered an advanced material which is the so-called functionally graded materials (FGMs) [1]. These materials are often fabricated by at least two distinct constituents with continuously varied material properties in a certain spatial direction. Thus, failures caused by the discontinuities of strain and stress fields can be reduced. Among them, the ceramic-metal composite merits consideration as a priority choice in structural applications due to their outstanding advantages produced from the synergy. Indeed, the metal works very well under mechanical impacts, whilst the ceramic is strongly suitable for standing high temperature environments. Accordingly, a large number of research papers on using such a mate-

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