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Vibration of FG-GPLs eccentric annular plates embedded in piezoelectric layers using a transformed differential quadrature method

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Highlights

- Providing a systematic solution procedure for a complex vibrational problem.
- Directly discretization of governing equations in physical domain.
- Investigating the vibrational behavior of FG-GPLRC eccentric annular plates.
- Studying the effects of piezoelectric layers on the vibrational behavior of the system.
- It is found that the piezoelectric layers decrease the stiffening effects of GPLs.

Abstract

In this paper, a transformed differential quadrature method (TDQM) for the free vibration analysis of functionally graded (FG) multilayer nanocomposite eccentric annular plates reinforced by graphene nanoplatelets (GPLs) and embedded in piezoelectric layers is developed. In this regards, a suitable conformal mapping is utilized to calculate the transformed weighting coefficients of the differential quadrature method (DQM) in physical domain which enables one to directly discretize the partial differential equations in the reference domain. The modified Halpin–Tsai model is employed to estimate the effective mechanical properties of the nanocomposites. The governing equations are derived based on the first-order shear deformation theory (FSDT) using Hamilton's principle and Maxwell's equation. The numerical results show that the TDQM has a very good convergence rate. Furthermore, the accuracy and reliability of the proposed method are verified by comparing the results with those obtained by simulating some problems via ABAQUS software and also, in the limit cases with those available in the literature. The effects of GPLs weight fractions, number of GPLs reinforced layers, distribution types of GPLs, different boundary conditions and various

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plate geometrical parameters such as the plate thickness, piezoelectric layers thickness, external electrical voltage and off-set parameter on the natural frequency parameters are investigated.

Keywords: Free vibration; Eccentric circular plate; Graphene platelets; Transformed differential quadrature; Piezoelectric layers

1. Introduction

In recent years, the demand for high performance smart structures has been increased considerably. This stimulates the scientists in the field of composite materials to seek for new nanocoating [1,2] or reinforcements with superior material properties over the conventional micro-sized fibers such as glass, Kevlar and carbon fibers to fabricate advanced nanocomposites. In this regards, recently, carbon-based nanomaterials such as carbon nanotubes (CNTs) [3–5] and graphene and its derivatives such as graphene platelets (GPLs) and graphene oxide (GO) [6–15] have been used to create the polymer based nanocomposites with enhanced mechanical and other material properties. But, it has been reported that the development of CNTs reinforced nanocomposite materials have practically several challenges, such as high manufacturing costs, difficulty to achieve uniform dispersion without agglomeration and highly anisotropic characteristics of CNTs [7–9]. As other promising nano-sized reinforcements, which can overcome or reduce these shortcoming of CNTs, are graphene and its derivatives such as GPLs and GO. Graphene has shown great potential to become a candidate for polymer reinforcement since its discovery in 2004. This is because graphene has excellent mechanical properties, lower cost than CNTs, high specific area and two-dimensional geometry (planar), which can improve its reinforcing effects [6]. For example, it has been shown experimentally that an addition of 0.1% weight fraction of GPLs into epoxy matrix can increase the Young's modulus of the nanocomposite by 31% while only an increase of 3% can be achieved by CNT fillers [6].

In order to use the reinforcement phase effectively and increase the performance of nanocomposites for a particular value of reinforcement weight fraction, it has been suggested to scatter them in the preferred direction with the engineered gradients [16]. The material properties of the resulting nanocomposites, or the so called functionally graded nanocomposites, vary spatially in a continuous manner. For the structural elements made of nanocomposites, the reinforced phases are usually scattered in the thickness direction, however, it may be dispersed in both the thickness and in-plane directions in a similar manner as the conventional functionally graded materials [17].

On the other hand, the progress in technology of smart piezoelectric materials provides the ability to construct intelligent materials with self-diagnosis function and adaption to the environment change [18]. Hence, the different types of structural elements made of the aforementioned new advanced composites integrated with piezoelectric layers can be used to build up advanced smart structures for modern industries.

As one of the important and essential structural components, annular plates with and without eccentricity have been widely used in different mechanical, civil, aerospace, nuclear and reactor industries. In this regard, some studies have been focused on the free vibration analysis of homogeneous and non-homogeneous annular plates with and without piezoelectric layers (see for example Refs. [19–36]) and homogeneous eccentric annular plates [37–46]. However, to the best of authors' knowledge, not only the vibrational behavior of non-homogeneous annular plates with eccentricity but also those of CNTs or GPLs reinforced nanocomposite annular plates without eccentricity have not been investigated in the open literature yet. In addition, the available studies concerned with vibration of the structural elements made of GPLs reinforced composite material are little in comparison to those of ones with homogeneous or other composite materials. However, the study of the mechanical behavior of graphene-based nanocomposites is becoming increasingly popular in both academia and industry. In continuation, some of the relevant researches will be reviewed briefly.

Feng et al. [47] studied the effects of the weight fraction and distribution of GPLs, size of GPL nanofillers, the total number of layers and boundary conditions on the nonlinear natural frequencies of functionally graded multilayer graphene platelets reinforced composite (FG-GPLRC) beams based on Timoshenko beam theory by considering the von Kármán geometric nonlinearity assumption. They employed the Ritz method to discretize the equations of motion in spatial domain. Song et al. [48] analyzed the free and forced vibration of the simply supported FG-GPLRC rectangular plates based on the FSDT using the Fourier series expansion. They employed modified Halpin–Tsai model