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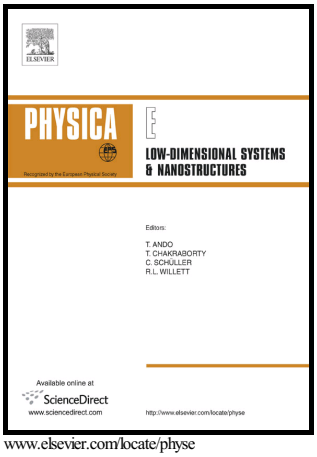

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Vibration analysis of defective graphene sheets using nonlocal elasticity theory

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ABSTRACT

Many papers have studied the free vibration of graphene sheets. However, all this papers assumed their atomic structure free of any defects. Nonetheless, they actually contain some defects including single vacancy, double vacancy and Stone-Wales defects. This paper, therefore, investigates the free vibration of defective graphene sheets, rather than pristine graphene sheets, via nonlocal elasticity theory. Governing equations are derived using nonlocal elasticity and the first-order shear deformation theory (FSDT). The influence of structural defects on the vibration of graphene sheets is considered by applying the mechanical properties of defective graphene sheets. Afterwards, these equations solved using generalized differential quadrature method (GDQ). The small-scale effect is applied in the governing equations of motion by nonlocal parameter. The effects of different defect types are inspected for graphene sheets with clamped or simply-supported boundary conditions on all sides. It is shown that the natural frequencies of graphene sheets decrease by introducing defects to the atomic structure. Furthermore, it is found that the number of missing atoms, shapes and distributions of structural defects play a significant role in the vibrational behavior of graphene. The effect of vacancy defect reconstruction is also discussed in this paper.

KEYWORDS: Graphene sheet, Defect, Fundamental frequency, Nonlocal elasticity theory, Defect reconstruction

1 INTRODUCTION

Experimental and theoretical studies in the fields of microstructures and nanostructures increased substantially after the synthesis and characterization of carbon nanotubes by Iijima in 1991 [1]. Eventually, with the development of these fields, graphene sheets drew attentions to themselves, because of their unique mechanical, electrical and electronic properties. Nowadays, graphene sheets are widely used in nano-sensors, nano-oscillators, electrical batteries, nano-composites, and nano-electromechanical resonators [2, 3]. As a result, investigating the mechanical characteristics of graphene sheets is inevitable.

Among various mechanical characteristics of graphene sheets, their vibrational behavior is of great importance. Due to difficulties in conducting experiments to determine the mechanical properties of graphene sheets, generally analytical methods, numerical modelings, and molecular dynamics simulations are used to determine their vibrational characteristics. Up until now, several studies have been done on the vibration of graphene sheets. Murmu and Pradhan [2] employed an analytical method using the separation of variables to investigate the effect of nonlocal parameter on the vibration of graphene sheets. Pradhan and Phadikar [4] calculated natural frequencies of graphene sheets analytically by modifying the classical laminated plate theory (CLPT) and the first shear deformation theory (FSDT) using nonlocal elasticity theory. Hosseini-Hashemi et al. [5] used the Mindlin theory and introduced some potential and auxiliary functions to study the free vibration of graphene sheets. Zhang et al. [6] implemented an element-free kp-Ritz to investigate the free vibrational behavior of a single-layered graphene sheet (SLGS). Moreover, Zhang et al. [7] used nonlocal elasticity theory and CLPT to study the vibrational behavior of bilayer graphene sheets (BLGSs) in a magnetic field.

Zhang et al. [8] also analyzed nonlinear large deformation of SLGSs using an element-free kp-Ritz. Zhang et al. [9] studied the transient analysis of SLGSs via an element-free kp-Ritz method. Ansari et al. [10] implemented the finite element method (FEM) to analyze the free vibration of multi-layered graphene sheets. Ansari et al. [11] investigated the vibration of single-layered graphene sheets (SLGSs) using a nonlocal continuum plate model and then validated the calculated results with ones obtained by the molecular dynamics simulations. Pradhan and Kumar [12] studied the small-scale effect on the vibration analysis of orthotropic SLGSs. They employed the differential quadrature method (DQM) to solve governing equations derived using the nonlocal elasticity theory. Xing and Liu [13] found exact solutions for the free vibration of thin orthotropic rectangular plates. This problem solved for various boundary conditions and validated with results obtained by FEM. Setoodeh and Malekzadeh [14] investigated the free vibration analysis of orthotropic SLGSs using the nonlocal Mindlin plate theory and employing the DQM.

On the other hand, graphene sheets are assumed perfect, i.e. without any defects, in the aforesaid papers. Nonetheless, mass production of perfect graphene sheets can be a formidable task [15]; hence, structural defects do exist in graphene, like in any other real material [16]. Researches have showed that even a small number of defects